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DEVELOPMENT OF COST-OPTIMIZED INSULATION SYSTEM FOR USE IN LARGE SOLID ROCKET MOTORS

Volume I: Task I - Survey and Screening

T-3626

by:

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and

D. L. Nachbar, Project Manager, LMISD Program

AEROJET-GENERAL CORPORATION

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS3-11224
J. J. Pelouch, Jr., Project Manager

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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FINAL REPORT

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Volume I: Task I - Survey and Screening

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Prepared for:

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Contract NAS3-11224

NASA Lewis Research Center
Cleveland, Ohio
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FOREWORD

The insulation development work described herein, which was conducted by the Solid Rocket Division of Aerojet-General Corporation, was performed under NASA Contract NAS3-11224. The work was accomplished under the management of the NASA Project Manager, Mr. J. J. Pelouch, Jr., Chemical Propulsion Division, NASA-Lewis Research Center.

Special acknowledgements for work accomplished in Task I are accorded to Messrs. A. A. Stenerson and W. Bradley, Material Technology Department, for material property analyses, and to Messrs. C. J. Rogers, P. L. Smith, and R. F. Russ, Propellant Development Department, for material processing analyses.

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ABSTRACT

A program to develop a cost-optimized insulation system for large solid rocket motors was conducted by Aerojet-General Corporation under Contract NAS3-11224. Four tasks were derived to accomplish the program objective: Task I, Survey and Screening; Task II, Process Demonstration; Task III, Material Performance Determination; and Task IV, Preparation of 260-in.-dia full-length motor insulation system Design and Process Plan. Task I, which has been completed and is the subject of this report, was accomplished in three phases. Initially, a literature survey revealed thirty firms or facilities engaged in research, development, and production of insulation materials which were applicable to large rocket motors. Of the forty-six materials recommended by potential suppliers, twenty materials, including four pressure-cured, six trowelable, five castable, and five sprayable, were selected for evaluation in Task I. In Phase I of Task I, the selected twenty materials were subjected to a series of property measurements; these measurements included composite tensile strength/modulus, density, ambient pot life, viscosity build-up, bond line tensile/shear, water absorption, thermal diffusivity, thermal conductivity, heat capacity, heat of combustion, and thermogravimetric analysis. The objective of this Task I phase was to establish which of the candidate materials exhibit properties most applicable to large solid-rocket motors. Three 20-in.-dia heavyweight motor tests were conducted in Phase II to determine the relative erosion resistance of the candidate materials. The motors operated at 640 psia over a web burning duration of 17.6 sec. A malfunction, caused by improper propellant cartridge installation, occurred in the third motor and necessitated a fourth motor test. Six candidate material specimens, plus V-44 and V-61 control specimens, were evaluated in each motor. Initial Mach numbers and material thickness losses were obtained from pre- and posttest profile measurements. Plots of material thickness loss rates as a function of Mach numbers provided a comparison of the erosion resistance of each material relative to the erosion performance of the V-44 control. A tradeoff rating using data from Phases I and II yielded a recommendation of ten materials, plus the specified V-44 control, for further evaluation in Tasks II and III of the program. Approval of the material recommendations by the NASA-LeRC Project Manager concluded the Task I effort.

NASA report numbers and corresponding volume numbers are as follows:

CR-72581	Volume I
CR-72582	Volume II
CR-72583	Volume III
CR-72584	Volume IV

I. SUMMARY

The objective of the Large Motor Insulation System Development (LMISD) Program is to evaluate low-cost insulation materials which are applicable to large solid-propellant rocket motors. Four tasks were derived to accomplish the planned objective. Task I, which is completed and the subject of this report, involved a survey of available materials applicable to large motors; selection of twenty candidate materials, including Gen-Gard V-44 and V-61 as controls; measurement of candidate material physical, chemical, mechanical, thermal, and adhesive properties; evaluation of material erosion resistance in three solid-propellant motor tests; evaluation of property measurement and motor test data; and selection of twelve materials, including V-44 and V-61 controls, for further evaluation in Tasks II and III. Task II will be a process demonstration, in which candidate materials selected in Task I are installed into a 54-in.-dia motor chamber. Task III will include material performance determinations in five solid-propellant motor tests. Task IV will be the preparation of a 260-in.-dia full length motor cost-optimized insulation system design and process plan, using materials selected on the basis of data obtained from Tasks II and III. This report summarizes in detail the Task I effort.

The Task I materials survey consisted of two parts: a literature survey and supplier consultations. The literature survey concentrated on insulation materials and processes developed and evaluated in 100-, 120-, 156-, and 260-in.-dia motors. From this survey, a list of thirty firms or facilities engaged in research, development, and production of insulation materials was prepared. Letters requesting material recommendations and current data on pressure-cured, trowelable, castable, and sprayable insulators were sent to thirty suppliers. Forty materials were recommended by eighteen of the thirty suppliers contacted; of these forty materials, twenty-two were of the pressure-cured group, nine were trowelable, nine were castable, and six were sprayable. Only one phenolic/crepe-paper material was not applicable to specified material categories. Material data received from the various suppliers were collated and evaluated. Following intensive review, the following twenty materials were recommended for Task I evaluation:

Pressure-Cured

Gen-Gard V-44 (Control)	General Tire & Rubber Co.
Orco 9250	Ohio Rubber Co.
USR 3800	Uniroyal, Inc.
USR 3804	Uniroyal, Inc.

I. Summary (cont)

Trowelable

Gen-Gard V-61 (Control)	General Tire & Rubber Co.
IBT-100	Aerojet-General Corp.
IBT-106	Aerojet-General Corp.
LPL-44	Lockheed Propulsion
TI-H704B	Thiokol Chemical Corp.
Gen-Gard V-4011	General Tire & Rubber Co.

Castable

IBC-101	Aerojet-General Corp.
40SD-80	American Poly-Term Co.
Castable Carbon	Atlantic Research Corp.
RTV-511	General Electric Corp.
Avcoat 8021	AVCO Corp.

Sprayable

IBS-107	Aerojet-General Corp.
IBS-108	Aerojet-General Corp.
IBS-109	Aerojet-General Corp.
Avcoat II	AVCO Corp.
PR-1933	Products Research & Chem. Corp.

The foregoing material recommendations were approved by the NASA-LeRC Project Manager. This concluded the materials survey portion of Task I.

Material procurement was initiated for Phase I property measurements and Phase II solid-propellant motor tests; Phase I and Phase II of Task I were accomplished concurrently. Lockheed Propulsion Company's LPL-44 trowelable, PBAA insulation could not be procured within the allotted expenditure. As a result, 93-104 castable silicone rubber, manufactured by Dow Corning, was substituted for LPL-44; the NASA-LeRC Project Manager concurred with this substitution. One other material change was made later in the Task I effort. During processing of candidate materials into the test motors, an acceptable specimen of castable carbon could not be obtained because of its viscosity and cure characteristics. As a result, a specimen of IBC-111 was used instead. IBC-111,

I. Summary (cont)

manufactured by Aerojet-General Corporation, was a castable version of trowelable, PBAN-epoxy IBT-100, and was developed originally as an exit cone liner for the M-1 liquid engine program. IBC-111 contains Refrasil (high purity silica) in place of carbon black and asbestos.

In the Phase I effort, the twenty candidate materials selected from the survey were subjected to the following physical, chemical, mechanical, thermal, and adhesive property measurements:

Composite Tensile Strength Modulus	Thermal Diffusivity
Density	Thermal Conductivity
Pot Life/Viscosity Build-Up	Thermogravimetric Analysis
Bondline Tensile/Shear Strength	Heat Capacity
Water Absorption	Heat of Combustion

The objective was to establish which of the candidate materials possess properties most applicable to 260-in.-dia motor operating requirements. The data from the property measurement are summarized in this report.

Phase II included the design and manufacture of a 20-in.-dia solid-propellant insulation test motor; requirements for the test motor were as follows:

Throat Diameter, in.	1.8
Operating Pressure, psia	600 ± 25
Burning Duration, sec	19
Specimen Exposure Environment	Mach zero to 0.3
Propellant	ANB-3254

The aft closure/nozzle configuration included a dual entrance section. A 45-degree approach was used from the attachment flange to an area ratio of approximately 4:1. From this area ratio to the throat a 10-degree nozzle approach was used to expand the desired zero to 0.3 Mach region.

Government-furnished propellant cartridges were used. The 20-in.-dia by 20-in.-long pressure-vessel was fabricated from an ASTM A235 steel forging. The aft closure was ASTM A36 steel. Six candidate material specimens, plus V-44 and V-61 control specimens, were installed into the aft closure. Pre- and posttest insulation specimen profiles were measured and recorded using a Portage Layout Machine; profile measurements were used to determine initial Mach numbers at the specimen surfaces and the material thickness loss.

I. Summary (cont)

Three Task I insulation test motors, identified as S/N's I-1, I-2, and I-3, were test fired on 18 October, 31 October, and 22 November 1968, respectively. The attempt to test fire motor S/N I-3 resulted in a 1.9 sec hangfire, after which time the motor chamber pressure increased abruptly to over 1000 psia, causing failure of the aft flange joint bolts and ejection of the closure. Neither the motor pressure-vessel nor the aft closure were damaged significantly. This malfunction was attributed to improper installation of the propellant cartridge. The S/N I-3 components were repaired, rehabilitated, and reassembled; the motor, reidentified as S/N I-3A, was test fired successfully on 20 December 1968.

The following is a summary of the insulation material specimens tested in each motor:

Motor S/N I-1	Motor S/N I-2	Motor S/N I-3A
V-44	V-44	V-44
V-61	V-61	IBT-100 (3)
IBT-100	40 SD-80	Orco 9250
IBT-106	RTV-511	USR 3800
IBC-101	IBC-111 (1)	USR 3804
IBS-107	Avcoat II	TI-H704B/V-61
IBS-108	PR 1933	4011
IBS-109	TBS-758 (2)	Avcoat 8021

Notes: (1) Replacement material for castable carbon.
(2) Used in place of 93-104.
(3) Used in place of 93-104 specimen.

The following is a summary of motor performance:

	S/N I-1	S/N I-2	S/N I-3	S/N I-3A
Web Average Pressure, psia	640	641	1.9 sec	634
Maximum Pressure, psia	680	668	Hangfire	662
Web Duration, sec	17.6	17.7	Closure Ejected	17.6

I. Summary (cont)

Following each test, the motor was visually inspected, the char layer was removed, and posttest profiles were obtained. Using pre- and posttest profiles, each material thickness loss was measured at specified locations normal to the specimen surfaces; gas flow Mach numbers at the specimen surfaces were calculated. Thickness loss rates were calculated, and a visual comparison of each candidate material performance relative to V-44 was obtained by plotting the thickness loss rate as a function of Mach number, then drawing the most representative line through the data points for each material. Material performance relative to V-44 are summarized as follows:

1.	USR-3800	8.	V-44 (control)	15.	IBS-108
2.	Orco 9250	9.	IBS-109	16.	Avcoat II
3.	V-61	10.	V-4011	17.	RTV-511
4.	IBT-100	11.	USR-3804	18.	PR-1933
5.	IBS-107	12.	40SD-80	19.	TBS-758
6.	IBC-111	13.	IBC-101		
7.	IBT-106	14.	TI-H704B		

Avcoat 8021 - No meaningful data - 93-104 and Castable Carbon not tested.

The objective of Phase III preliminary evaluation was to review the data obtained from Phases I and II, and, on the basis of this data, select eleven materials, including V-44 control for further evaluation in Tasks II and III. Independent trade-off evaluations were made based on the following characteristics: performance; cost; compatibility with propellant/liner/steel; thermal, physical, chemical, mechanical, and adhesive properties; and ease of repair/removal. A significance factor was applied to each characteristic, with major significance placed on performance and cost. The silicone rubber materials, 93-104, RTV-511, and PR-1933, were eliminated from further consideration because of their poor erosion resistance and bonding characteristics with SD 850-2 liner. An unacceptable, short pot life was the reason for eliminating V-61 and V-4011; V-4011 also experienced poor bonding to SD-850-2 liner. The following materials were recommended for Task II and III evaluation:

Pressure-Cured	Task II	Task III
Gen-Gard V-44	No demonstration	Control specimen
USR-3800	No demonstration	1 motor test
Trowelable		
IBT-100	Demonstrate as head insulator	1 motor test
IBT-106	Demonstrate as head/ sidewall insulation	1 motor test
TI-H704B	Demonstrate as head sidewall insulation	1 motor test

I. Summary (cont)

	Task II	Task III
Castable		
IBC-101	No demonstration	1 motor test
IBC-111	Demonstrate as head insulator	1 motor test
40SD-80	Demonstrate as head insulator	1 motor test
Sprayable		
IBS-107	Demonstrate as sidewall insulator/propellant boot	1 motor test
IBS-109	Demonstrate as sidewall insulator/propellant boot	1 motor test
Avcoat II	Demonstrate as sidewall insulator	1 motor test

The approval of the foregoing material recommendations by the NASA-LeRC Project Manager concluded the Task I effort of the LMISD Program.

II. INTRODUCTION

A. PURPOSE OF REPORT

This document is the first volume in a series of final reports dealing with the major tasks of the Large Motor Insulation System Development (LMISD) Program, Contract NAS3-11224. This series of reports constitutes the LMISD Program final report. This report summarizes in detail the Task I effort for the LMISD Program.

B. PROGRAM BACKGROUND

In the design of the insulation system for Motors 260-SL-1, Sl-2, and SL-3, which were test fired successfully at the Aerojet-Dade Division, Florida, the main emphasis was placed on reliability, so that the insulation system essentially was zero-risk to the program. For this reason, Gen-Gard V-44 rubber was selected as the insulating material because of its demonstrated reliability and predictable performance in numerous prior rocket motor programs. V-44 rubber insulation components were vulcanized on mandrels to the required configuration at high temperature and pressure. These cured components were transported to the motor processing facility and secondarily

II. B. Program Background (cont)

bonded into the motor chamber interior. This technique, although highly reliable, involved the use of substantial tooling and labor, both at the rubber component manufacturing facility and at the motor processing facility.

As the 260-in.-dia motor demonstration program had been completed successfully, it was now possible to consider cost optimization of the large motor insulation system using Gen-Gard V-44 material properties, processing techniques, and performance as comparative baselines. Several materials showed potential for large solid motor applications at a cost savings through reduction in raw materials, processing, tooling, and labor. Previous work accomplished under Contract AF 04(611)-11609, Investigation of Insulation Materials for Multiple Restart Applications, and Contract NAS3-12083, Preparation of Insulation Material Monograph, identified low cost material previously thought to be unsuitable for large motor applications.

Analytical and experimental investigation of candidate materials followed by selective screening and design definition, using common ground rules, was the necessary first step toward the qualification of a cost-optimized insulation system for 260-in.-dia motors. The development program described herein was derived to accomplish this first step.

C. PROGRAM OBJECTIVES

The objectives of the LMISD Program are to evaluate insulation materials applicable to large solid-propellant motors, select the best materials based on cost, processing capability, and performance, and relate the selected materials to an insulation system design for a 260-in.-dia full-length motor. Four tasks were derived to accomplish the program objectives. Task I, which is the subject of this report, involved a survey of available materials, selection of twenty candidate materials, evaluation of candidate material properties and thermal performance, and selection of twelve materials for further evaluation in Tasks II and III. Task II was the process demonstration, in which the candidate materials selected in Task I were installed into a 54-in.-dia motor chamber. Task III included candidate material performance determinations in five solid-propellant motor test firings. Task IV was the preparation of a design and process plan for a 260-in.-dia full-length motor cost-optimized insulation system using materials and processes selected from Tasks II and III.

D. SCOPE OF EFFORT

This report volume summarizes in detail the Task I effort for the LMISD Program. The following work was accomplished:

1. A survey of insulation materials applicable to large solid rocket motors.

II.D. Scope of Effort (cont)

2. Consultation with insulation material suppliers regarding availability of candidate materials.

3. Selection of twenty materials for evaluation in Task I.

4. Determination of physical, chemical, thermal, mechanical, and adhesive properties of twenty candidate materials.

5. Design, manufacture, and test of three solid-propellant motors to evaluate thermal performance of twenty candidate insulation materials.

6. Evaluation of the properties and thermal performance of candidate materials.

7. Selection of twelve materials for further evaluation in Tasks II and III for the LMISD Program.

E. PROGRAM SCHEDULE

A program schedule is shown in Figure 1.

III. MATERIAL SURVEY

The materials survey consisted of two parts: a literature survey and supplier consultations. Materials applicable to the following categories were investigated:

Chemical Groups

synthetic rubber and synthetic rubber/filler combinations

phenolic filler, phenolic/natural rubber/filler, and phenolic/synthetic rubber/filler combinations

Physical Groups

pressure cured components secondarily bonded into place

ambient cured or vacuum cast components secondarily bonded into place

room or elevated temperature cured materials troweled or cast into place

room or elevated temperature cured materials sprayed into place

III. Material Survey (cont)

Primary emphasis was placed on the investigation of trowelable, castable, and sprayable materials, preferably those capable of being processed at the motor manufacturing facility. Only those materials meeting the following requirements were considered:

> the material must have no previous unreliable usage history in solid-propellant motors
>
> suppliers of any given material must be able to manufacture the material in quantities necessary for large motor applications without extensive facility modifications; assumed motor production rate was 4 units per year
>
> supplier's quality control capability must be adequate for the intended material use.

A literature survey on insulation materials and processes developed and evaluated in large motor programs, 100-, 120-, 156-, and 260-in.-dia motors, was conducted. A list of the reports reviewed in the literature survey are shown in Figure 2. Based on this survey, a list of principal suppliers and firms or facilities engaged in research, development, and production of all types of insulation materials was prepared. Letters requesting current data on pressure-cured, trowelable, castable, and sprayable insulation materials which met the foregoing requirements, were sent to the following suppliers:

General Tire & Rubber Co.

Lockheed Propulsion Co.

Thiokol Chemical Corp.

United Technology Center

American Poly-Therm Co.

Kirkhill Rubber Co.

Ohio Rubber Co.

Atlantic Research Corp.

Uniroyal, Inc.

West American Rubber Co.

U. S. Polymeric, Inc.

AVCO Corp.

Ferro Corp.

Raybestos Manhattan

Fiberite West Coast Corp.

U. S. Naval Ordnance Laboratory

Hercules, Inc., Allegany Ballistics Lab.

Dow Corning Corp.

General Electric Co.

Union Carbide Corp.

Insulation Technology, Inc.

H. I. Thompson Fiberglass Co.

B. F. Goodrich Co.

Goodyear Tire & Rubber Co.

Arrowhead Products

Narmco Materials Division

Garlock, Inc.

Product Research Co.

Minnesota Mining & Manufacturing Co.

Aerojet-General Corporation

III. Material Survey (cont)

A sample of the letter which was sent to each supplier is shown in Figure 3. The data requested included available quantities; delivery time; raw material cost for various quantities; processing characteristics; adhesive bonding data; use history; and mechanical, physical, chemical, and adhesive properties. Personal contacts were made with responding suppliers whose material or process was directly applicable to large motor insulation systems.

Forty-six materials were recommended by eighteen of thirty suppliers contacted. Of the forty-six materials recommended, twenty-two were of the pressure-cured group, nine were trowelable, nine were castable, and six were sprayable. Figure 4 is a summary of insulation materials recommended by responding suppliers. Only FM-5272, a phenolic/crepe-paper material recommended by U. S. Polymeric, was not applicable to the specified material categories. Material data received from suppliers are summarized in Figures 5 and 6.

The forty-six recommended insulation materials were reduced to the thirty materials shown in Figure 7. In general, one material was selected from each of the pressure-cured group classes shown in Figure 4, plus the Gen-Gard V-44 control. Only one material from the butyl, SBR-phenolic, and isoprene classes were recommended and available for selection. The lower cost material was selected from each of the NBR, NBR-phenolic, and phenolic-carborazole classes. The two supplier recommended materials from the newly developed ethylene-propylene class were selected. Also, since six silicone rubber materials were recommended by suppliers, two materials from this class were included with the thirty materials. All nine of the supplier recommended trowelable materials were included in Figure 7. Of the nine castable materials recommended, five were selected. Two of the polyurethane materials recommended by American Poly-Therm, 40SA-2 and 40SA-40, were eliminated becuase of their high cost. Also, one of the silicone rubber materials recomended by Dow Corning, 93-073, was excluded because of its similarity to 93-104. Five of the six recommended sprayable materials were selected. IBS-105 was eliminated because of its chemical and physical property similarity to IBS-109.

The reduction of thirty materials down to twenty materials recommended for evaluation in the Task I property measurements and thermal tests was accomplished strictly on a cost basis. Since the LMISD program was directed toward trowelable, castable, and sprayable groups, the recommended twenty materials included a minimum of five materials from these material groups. The list of the twenty materials selected for Task I evaluation is shown in Figure 8.

Only three materials other than V-44 control were selected from the selected from the pressure-cured group. Orco 9250 (NBR class), USR 3804 (EPR class), and USR 3800 (NBR-phenolic class) were the lowest cost materials. Six trowelable materials were recommended for further evaluation. The cost

III. Material Survey (cont)

differential between the silicone class and the other classes made the selection clear. Gen-Gard 4011 is a relatively new trowelable material being developed by GT&R for low temperature applications. Although there currently is no low temperature application involved in large motor insulation systems, 4011 potentially offered processing and ablative potential and was worth evaluation in this program. The higher cost DC 93-104 was eliminated from the castable group. Only five sprayable materials were available from the thirty materials; thus, those five materials were recommended for further evaluation.

The recommendation of the twenty materials shown in Figure 8 was approved by the NASA-LeRC Project Manager, thus completing the material survey portion of the Task I effort.

IV. PHASE I - MATERIAL PROPERTY MEASUREMENTS

In this phase of the Task I effort, the twenty materials selected from the materials survey (Figure 8) were subject to the following physical, chemical, mechanical, thermal, and adhesive property measurements:

Composite tensile strength and modulus

Density

Pot life and viscosity

Bond line tensile and shear strength

Water absorption

Thermal diffusivity

Thermal conductivity

Thermogravimetric analysis

Heat capacity

Heat of combustion

The objective of this task was to establish which of the candidate materials possess properties most applicable to 260-in.-dia motors. Property measurement test procedures are described in Appendix I.

Insulation material procurement for the Phase I property measurements and Phase II thermal test were initiated concurrently. Suppliers of the twenty materials shown in Figure 8 were contacted and arrangements were made to procure approximately 25 lb of each material for all of the Task I tests. A material procurement summary is shown in Figure 9. Five materials were received as free samples. V-44 and V-61 materials were available as residual

IV. Phase I - Material Property Measurements (cont)

from the 260-SL-3 motor program. Raw materials for the IBT, IBC, and IBS formulations were available from Aerojet's overhead stock at the cost shown in Figure 5. Only 6 lb of TI-H704B material was received, necessitating the use of a small specimen in the test motor. A problem was encountered concerning procurement of Lockheed Propulsion Company's LPL-44 trowelable, PBAA insulation; a firm quotation of $6200 was received for 25 lb of this material, which amounted to $248/lb. Since the cost was beyond their advertised price and beyond the allotted expenditures for material procurement, a request was made to substitute Dow Corning 93-104 castable silicone rubber material for the LPL-44. The NASA-LeRC Project Manager concurred with this substitution and DC-93-104 material was procured.

Results of the property measurements are summarized in Figure 10. The following paragraphs summarize the pertinent results of each test.

A. MECHANICAL PROPERTIES

Tensile strength, elongation, modulus, and Shore A hardness values for 19 insulation materials are shown in Figure 10. Typical stress-strain curves are shown in Figure 11. Tensile strength values ranged from a high of 3332 psi for Avcoat 802, to a low of 82 psi for RTV-511. The basic requirement for insulation material is that its tensile strength must be equal to or greater than the propellant tensile strength. Measured tensile strength values of 260-SL motor propellants, ANB-3105 and ANB-3254 were as follows:

Propellant	Average Tensile Strength, psi	Motor
ANB-3105	118/101	260-SL-1/SL-2
ANB-3254	90	260-SL-3

RTV-511 silicone rubber was the only material that exhibited a tensile strength less than the maximum propellant strength of 118 psi, all other material tensile strengths were equal to or greater than 118 psi.

Modulus and Shore A hardness values ranged from a high of 35,958 psi and 90 for Avcoat 8021 to a low of 132 psi and 21 for PR 1933.

B. DENSITY

Measured density values at 100, 200, and 300°F are included in Figure 10; these data are presented graphically in Figure 12. There is no specific requirement regarding material density for large motor applications. However, density is a factor in the insulation design thickness versus total motor weight tradeoff.

IV. Phase I - Material Property Measurements (cont)

C. HEAT CAPACITY, HEAT OF COMBUSTION, THERMAL CONDUCTIVITY, AND THERMAL DIFFUSIVITY

Measured values for these four material properties are included in Figure 10; thermal diffusivity, thermal conductivity and heat capacity values are plotted versus temperature in Figures 13, 14, and 15, respectively. These properties are a measure of the capability of the material to resist thermal degradation. Previous insulation development work, Reference 21 in Figure 2, found that material thermal properties were related to ablation resistance.

D. BOND LINE TENSILE AND SHEAR STRENGTH

Bond line tensile and shear strength specimen test results are included in Figure 10. Because these were composite specimens (steel, primer, adhesive, insulation, liner, and propellant), the values shown reflect, for the most part, the propellant tensile and shear strengths. Previous values obtained in similar 260-SL-3 motor program tests were 150 psi tensile and 104 psi shear. Poor bonding between insulation and liner were experienced with the silicone rubber materials, RTV-511, 93-104 and PR1933, and with 4011 and Avcoat II. Bonding problems with the silicone rubber materials also were experienced during processing of insulation specimens into the test motor aft closure. Some reduction in strength values were recorded for the IBS-108 and -109 specimens; for these materials, failure occurred in the insulation-to-propellant interface.

E. POT LIFE

Material pot life and working consistency data, included in Figure 10, were recorded during processing of the test motor aft closure specimens.

F. VISCOSITY

Viscosity build-up curves for candidate trowelable, castable, and sprayable materials are shown in Figures 16, 17, and 18, respectively. The pot life of 4011 and V-61 were so short (<30 minutes) that meaningful viscosity data could not be obtained. As previously reported, only 6 lb of TI-H704B material were received; for this reason, there was insufficient material available for the extrusion tube rheometer viscosity measurement.

IV. Phase I - Material Property Measurements (cont)

G. THERMOGRAVIMETRIC ANALYSIS

Curves showing the thermogravimetric analysis conducted at a heating rate of 20°C/min are shown in Figure 19. These TGA curves showed that the castable carbon and the DC-93-104 materials were far superior to the other materials in thermal stability. Avcoat 8021 and 40SD-80 material decomposed rapidly in a temperature range from 300 to 400°C.

The TGA data were used in conjunction with a computer program to determine chemical kinetic rate constants required for the preparation of the Insulation Thermal Behavior Model in Task III. The kinetic rate constants required included the order of reaction, the frequency factor, and the activation energy.

H. WATER ABSORPTION

Results of the water absorption test series are included in Figure 10. Materials that previously exhibited unsatisfactory bondline tensile and shear strengths, 93-104, RTV-511, PR 1933, and 4011, were not subjected to the moisture absorption tests. In general, there appeared to be no significant degradation in the bond strengths after exposure to 50 and 90% RH, except for the IBS, IBC, and IBT materials. During the tensile/shear bond line strength tests conducted as part of the water absorption evaluation, the IBT, IBC, and IBS materials experienced propellant-to-insulator breaks after both 180°F drying and extended exposure to 50 and 90% RH. IBS-108 and IBS-109 experienced propellant-to-liner breaks also on the "as-received" specimens. The reasons for these propellant-to-liner breaks were due either to oxidation or post cure of the insulation surface during 180°F drying or to poor adhesive qualities in the propellant used for this test series. Bond line tensile/shear values are repeated in the following table for clarity of discussion.

	Tensile Shear, psi			
	"As-Processed"	After 180°F Drying	After 50% RH Exposure	After 90% RH Exposure
IBS-107	93/107 a	73/77 b	85/88 c	77/62 d
IBS-108	127*/71* a	63*/38* b	61*/42* c	56*/31* d
IBS-109	125*/82* a	86*/59* b	46*/32* c	74*/40* d
IBT-100	167/105 a	59*/53* b	32*/35* c	40*/69* d
IBT-106	161/108 a	104*/66* b	84*/92 c	59*/80 d
IBC-101	131/105 a	64*/63* b	61*/74* c	83*/69* d
IBC-111	96/189 b	103*/109* d	75/89 e	84/103 e

*Break at propellant-to-liner bond.
a, b, c, d, e, - Sequence of propellant batches used in this test series.

IV.H. Water Absorption (cont)

At first, the propellant used in specimen preparation was suspected of having potentially poor adhesive properties. This propellant was obtained from batches processed for the Propellant Improvement Program being conducted under NASA-LeRC Contract NAS3-12002. Relating tensile/shear values to the various propellant batches in the foregoing table showed no correlation between a specific propellant batch and propellant-to-liner breaks. Batches a, c, and d gave consistently high tensile/shear values (~170/130 psi), whereas batches b and e produced lower values (~100/150 psi). From this data, it was concluded that the propellant-to-liner breaks in the IBX materials were caused by surface oxidation or post-cure during the 180°F drying cycle. Apparently serious consideration must be given to using the SD 850-2 liner system with the IBX materials, particularly if the "as installed" insulation experiences long term storage or temperatures in excess of +135°F. However, the necessity for drying temperatures above 135°F appears remote, since the weight gain for the IBX PBAN-epoxy and CTPB materials was only 0.30 to 0.42% after prolonged exposure to a 50% RH environment. During Task III processing operations, additional double-plate specimens will be prepared to investigate the effect of an SD 850-2 liner system on the bond line tensile/shear strength values of IBX materials. One preliminary test was made during the moisture absorption evaluation series. Fresh SD 850-2 liner was applied to one of the IBC-111 specimens following 90% RH exposure. The measured tensile strength value was 108 psi; this value was significantly higher than the 84 psi value obtained for IBC-111 specimens without liner (see Note 10, Figure 10, Sheet 4).

Measured moisture weight gain values were as expected. Percent weight gain for the PBAN-epoxy, CTPB, and PBAA materials ranged from 0.30 to 0.42% after prolonged exposure to a 50% RH environment. USR 3804 ethylene-propylene material exhibited the lowest weight gain (0.36%) of the pressure-cured materials. USR 3800 and V-61 materials, which contain significant quantities of boric acid, experience higher weight gains of 1.51 and 1.65%, respectively. There was no apparent bond strength degradation for pressure-cured, 40-SD80, V-61, and TI-H704B materials after 180°F drying and prolonged exposure to 50 and 90% RH environments.

V. PHASE II - MATERIAL THERMAL TESTS

A. INSULATION TEST MOTOR DESIGN

Relative performance of the twenty insulation materials selected from the survey was measured in subscale solid-propellant motor tests. Requirements for the insulation test motor were as follows:

V.A. Phase II - Material Thermal Tests (cont)

Throat Diameter, in.	1.8 minimum
Operating Pressure, psia	600 ± 25
Burning Duration, sec	19 minimum
Specimen Exposure Environment	Mach 0 to 0.3
Propellant	ANB-3254

The insulation test motor configuration is shown in Figure 20. Detailed engineering drawings for the insulation test motor are shown in Appendix II. Three Task I motor tests were planned. Each test motor aft closure contained six candidate insulation specimens, plus a V-44 and V-61 specimen for control. A stress analysis summary of LMISD test motor components is shown in Figure 21.

The most difficult part of the Phase I Thermal Test (also Task III, Phase I, Material Performance Determination) was to obtain accurate insulation erosion data at the higher Mach number regions in a motor with a small nozzle size. Gas velocities from Mach 0.1 to 0.3 occurred in a relatively small region close to the motor throat. A 10-degree nozzle approach was used to expand this Mach number region. The observed thicknesses loss rate (TLR) of V-44 at Mach 0.3 in large motors is approximately 0.065 in./sec. At Mach 0.1, this is reduced to only 0.01 in./sec. This means that within 2.0 in., which is the true distance between the Mach 0.1 and the Mach 0.3 regions on the insulation surface the erosion rate differed by a factor of 6.5. The concern was that the region between Mach 0.1 and sonic flow (Mach 1.0) was so narrow that, for 20 sec of exposure, erosion at the higher Mach number regions would influence and distort erosion upstream at the lower Mach number regions. To ensure that usable erosion data were obtained from the motor tests, V-44 rubber specimens were included in each of the motor tests as a control. In this way, V-44 erosion was compared to the data currently available so that any distortions caused by the proximity of the high and low Mach number regions were identified. The erosion occurring in other candidate insulation materials was compared with V-44 rubber performance, and at least comparative information was available. To achieve this material comparison, it was necessary to establish an accurate means of inspecting pre- and posttest insulation specimen contours. Several methods of obtaining insulation contour measurements were investigated and evaluated for use on the LMISD Program; the methods investigated are summarized in Figure 22. The most accurate method appeared to involve the use of the Sheffield CORDAX 300 automatic coordinate measurement machine. However, limited access to the aft closure nozzle entrance section severely restricted the use and accuracy of this equipment. Re-evaluation of various inspection methods led to the selection of a Portage layout machine for measuring insulation specimen profiles. The inspection setup for layout of the test motor aft closure insulation specimen profiles is shown in Figure 23. Twenty-two measurements were made at each 45-degree radial location. The 0 degree index was the approximate centerline of the V-44 rubber control specimen.

V.A. Phase II - Material Thermal Tests (cont)

Only one fabrication problem was encountered which affected the insulation test motor design. Fabrication of the chamber (P/N 1145905-9) involved welding ASTM A36 steel plate flanges to each end of a 24-in.-O.D., Schedule 40, ASTM A53 seamless steel pipe. Upon completion of welding prior to final machining, the supplier reported that visual and radiographic inspection revealed unacceptable welds. The supplier was given the option of repairing the existing chamber or fabricating another. The supplier chose to fabricate a new chamber, and requested permission to fabricate the component from a rolled forging rather than chance another weld rejection. The forging approach was approved, and, after consultation with structural analysis personnel, ASTM A235, Class C-1 steel was selected. Hydrotest of the completed pressure-vessel was successful.

B. INSULATION TEST MOTOR PROCESSING

The test motor pressure-vessel cap and chamber were insulated with 0.2-in.-thick cured sheets of Gen-Gard V-44 rubber; the sheets were cut from residual cylindrical section insulation from the 260-SL-3 motor program ANB-3254 propellant cartridges were insulated with 0.2-in.-thick sheet of V-44, then bonded to the forward cap. The insulated chamber was assembled to the loaded cap. Polyethylene sheet was applied to the inside surface of the chamber, then the annulus between the chamber and insulated propellant cartridges were filled with SD-793 urethane potting material. The polyethylene sheet served as a release to simplify posttest disassembly.

Processing of insulation specimens into the test motor aft closure presented some processing problems due to limited access and a wide variety of material viscosity, pot life, and cure temperature characteristics. The castable, sprayable, and trowelable material specimens were installed into the first two closures; the third closure contained most of the pressure-cured specimens. The method selected for specimen processing is shown in Figure 24. An IBC-101 plug with eight plexiglass dividers was installed in the 10-degree nozzle entrance section. Sprayable and castable materials were injected into alternate sections through a Semco cartridge. After cure, the plug was removed and trowelable and pressure-cured materials were installed. Because there was some concern about the erosion resistance of RTV-511 and PR-1933, these materials were installed into the aft nozzle section over a 0.5-in. ply of V-44. This backup ply served to protect the closure in the event of severe erosion, as was experienced in the second closure. As previously mentioned in Section IV of this report, only 6 lb of Thiokol TI-H704B material were received. As a result, a 1.5-in.-wide by 1.5-in.-thick bar was cast and cured, then installed into the nozzle entrance section and potted into place with IBT-106 trowelable insulation material.

V.B. Insulation Test Motor Processing (cont)

TBS-758 and IBC-111 material specimens tested in the second motor were not on the original list of twenty materials. During processing of the second closure, attempts to bond Dow Corning 93-104 castable silicone rubber material specimen to an adjacent PR-1933 specimen were unsuccessful. Since no other specimens had been prepared, the Aerojet Project Manager approved substitution of General Electric TBS-758 silicone rubber material, so that the assembly and test schedule of the second motor would not be delayed. It was discovered later that the bonding problem was not due to the DC 93-104 material, but rather to the PR-1933; DC 93-104 was to be evaluated in the third motor test.

IBC-111 castable, PBAN-epoxy material was substituted for castable carbon. After numerous unsuccessful attempts to process an acceptable specimen in the aft closure, castable carbon was eliminated as a candidate insulation material. Its very short pot-life and cure hardness present processing problems totally undesirable for a large motor insulation system. IBC-111 is a castable version of IBT-100, and was developed as an exit cone liner for the M-1 liquid engine program. IBC-111 formulation is the same as that for IBT-100, except that the 20% carbon black and asbestos in IBT-100 is replaced with Refrasil (high purity silica). IBC-111 has exhibited good erosion resistance in the previous test program, and its potential was worth evaluating in the current program.

C. TEST RESULTS

The three Task I insulation test motors, identified as S/N's I-1, I-2, and I-3, were test fired on 18 October, 31 October, and 22 November, respectively. An attempt to test fire motor S/N I-3 on 22 November resulted in a 1.9 sec hangfire, after which time the motor chamber pressure increased abruptly to over 1000 psia, causing failure of the aft closure-to-chamber bolts. As will be described in detail in Section V.D. of this report, the S/N I-3 motor components were repaired, rehabilitated, and reassembled. The motor, reidentified as S/N I-3A, was test fired successfully on 20 December 1968.

The following is a summary of the insulation material specimens tested in each motor:

V.C. Test Results (cont)

Motor S/N I-1	Motor S/N I-2	Motor S/N I-3A
V-44	V-44	V-44
V-61	V-61	IBT-100
IBT-100	40SD-80	Orco 9250
IBT-106	RTV-511	USR 3800
IBC-101	IBC-111	USR 3804
IBS-107	Avcoat II	TI-H704B/V-61
IBS-108	PR 1933	4011
IBS-109	TBS-758	Avcoat 8021

The specimen locations for each motor are shown in Figures 25, 26, and 27.

The pressure-vs-time performance curves are shown in Figures 28, 29, and 30. The following is a summary of motor performance:

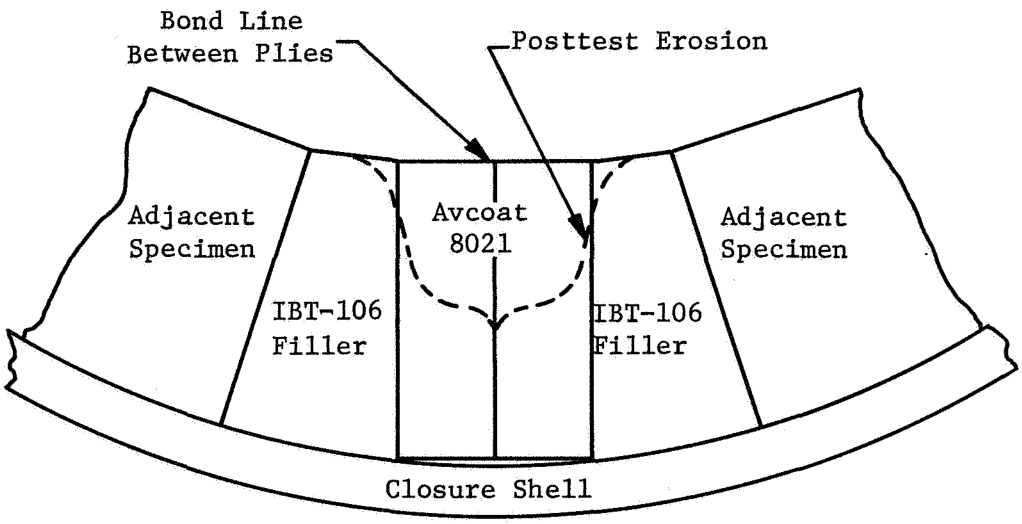
	S/N I-1	S/N I-2	S/N I-3	S/N I-3A
Web Average Pressure, psia	640	641	1.9 sec	634
Maximum Pressure, psia	680	668	Hangfire	662
Web Duration, sec	17.6	17.7	Closure Ejected	17.6

The 1128714-1, ANB-3254 propellant cartridges were cast from batch B-473 during 260-SL-3 motor propellant production at the Aerojet-Dade Division, Homestead, Florida. Liquid strand burning rate for propellant batch B-473 was 0.692 in./sec at 600 psia; the burning rate and exponent specified by NASA-LeRC for use in the LMISD Program was 0.692 in./sec at 600 psia and 0.35, respectively. The reported ANB-3254 burning rate for Motor 260-SL-3 was 0.729 in./sec at 600 psia. The 0.73 in./sec burning rate apparently applied to batch B-473, as evidenced by the higher than predicted web average pressures and shorter web burning durations.

The fired motors were returned to the processing area, disassembled, and visually inspected. Char thickness on all specimens except IBS-107 was approximately 0.1 in.; residual char thickness on the IBS-107 specimen was approximately 0.13 to 0.20-in., very similar to V-61 charring. Unusual erosion and charring patterns were evident in the PR 1933 and TBS-758 specimens. Also, an unusual erosion pattern was experienced by the Avcoat 8021 specimen in the Motor S/N I-3A. The Avcoat 8021 specimen was prepared by bonding two 0.25-in.-thick cured sheets together with Epon 921. A 2-in.-thick by 1-in.-wide block

V.C. Test Results (cont)

was cut from the material and bonded into the motor aft closure; IBT-106 was troweled around the specimen as shown previously in Figure 27. The Epon 921 bond line between the two 0.25-in.-thick plies was oriented perpendicular to the closure shell and essentially parallel to the closure center line. As shown in the following sketch, severe erosion occurred in the bond line, thus negating any meaningful performance data.



Cross Section of Avcoat 8021 Specimen

Following visual inspection, the char was removed from the specimens and posttest profiles were measured.

Pre- and posttest specimen profiles for each motor are summarized in Figures 31, 32, and 33. Individual specimen profiles for each material in each motor are presented in Appendix III. As previously noted, the objective of the Phase II motor tests was to obtain insulation material performance data for each of the materials relative to V-44 and relative to each other. Specific material thickness loss rates versus area ratio or gas flow Mach number were not possible because of the significant, non-linear variation in the area ratio over the 17 sec burning duration. The profile summaries of Figures 31, 32 and 33 were prepared by using the V-44 specimen pretest profile as the initial surface; then each material erosion profile was plotted relative to the V-44 surface.

V.C. Test Results (cont)

Using the pre- and posttest profiles recorded in Appendix III, each material thickness loss was measured at the 22 specified locations normal to the specimen surface. The initial area ratio (A/A*) and initial Mach number at each of the 22 locations in each closure were calculated from the recorded profiles. Thickness loss rates were calculated by dividing the measured thickness loss at each location by the web burning duration for each motor. Initial area ratios, initial Mach numbers at the specimen surface, thickness losses, and calculated thickness loss rates are summarized in Figures 34, 35, and 36.

Again, in an effort to compare visually the relative erosion resistances of the candidate materials, the measured thickness loss rates are plotted as a function of the initial Mach number at the specimen surface for each motor in Figures 37, 38, and 39. These graphs are not intended as a material design guide, but only to show the relative performance of each specimen, and were prepared by plotting the TLR-vs-Mach number data summarized in Figures 34, 35, and 36, then drawing the most representative line through the data points for each material. Material performance relative to V-44 are summarized as follows:

1. USR 3800
2. Orco 9250
3. V-61
4. IBT-100
5. IBS-107
6. IBC-111
7. IBT-106
8. V-44 (Control)
9. IBS-109
10. 4011
11. USR-3804
12. 40SD-80
13. IBC-101
14. TI-H704B
15. IBS-108
16. Avcoat II
17. RTV-511
18. PR 1933
19. TBS-758

Avcoat 8021 - No meaningful data. 93-104 and Castable Carbon - Not tested.

D. MOTOR S/N I-3 MALFUNCTION

1. Performance Analysis

An attempt to test fire Motor S/N I-3 on 22 November 1968 resulted in a 1.9 sec hangfire, after which time the motor chamber pressure increased abruptly to over 1000 psia. The nuts on the 48 aft closure-to-chamber joint bolts failed, and the closure and burning propellant cartridge were ejected. The insulated chamber and forward cap were undamaged; bolts in the

V.D. Motor S/N I-3 Malfunction (cont)

cap-to-chamber joint had yielded and were loose after the test. The insulated aft closure impacted on a revetment approximately 35 feet west of the W-1 test stand. Damage to the closure included a 3.0-in.-long depression on the outer circumference of the 25-in.-dia flange, substantial unbonding of DC93-104 specimen, and some superficial gouges in the forward face of several insulation specimens.

A pressure-vs-time performance curve for Motor S/N I-3 is shown in Figure 40. The igniter functioned normally for approximately 0.2 sec, attaining a maximum pressure of 158 psia at 0.08 sec. The calculated maximum pressure of a 300 gram boron-potassium nitrate pellet igniter fired in this test motor free-volume is 152 psia. The LMISD igniter output is much greater than the design requirements, shown as follows:

Characteristics	LMISD Igniter	Design Requirements
Induced Pressure, psia	158	20, minimum
Heat-flux, cal/cm^2-sec	1480	70, minimum
Total available energy, cal/cm^2	312	40, minimum

It is evident that the igniter used in Motor S/N I-3 functioned as designed and delivered sufficient energy for propellant ignition. This conclusion can be substantiated further by the fast, reproducible, ignition performance observed in Motors S/N I-1 and I-2, and subsequently in Motor S/N I-3A.

Having concluded that igniter performance was not the cause of the hangfire, the next logical suspect area was the exposed propellant grain surface. Two possibilities exist; either the propellant surface was contaminated or the propellant cartridge was installed so that the restricted face rather than the propellant face was exposed.

As previously stated, the test motor cap and chamber were undamaged; the only rehabilitation required was replacement of the 48 bolts and nuts. Major sections of the cartridge plastic sleeve and insulation were found in the vicinity of the test bay. The most significant item found was the 0.25-in.-thick, SD850-2 propellant face restrictor. The restrictor (17-in.-dia) was in one piece, and was charred on both sides. The fact that this propellant restriction was found outside of the motor and essentially intact indicated that the propellant cartridge either was improperly bonded or was improperly installed.

Close inspection of the aft closure after cleaning revealed a 17-in.-dia indentation in the insulation. The full diameter indentation was 0.06 to 0.12-in.-deep, depending upon the material specimen hardness.

V.D. Motor S/N I-3 Malfunction (cont)

Apparently the 17.5-in.-O.D. propellant cartridge was unbonded. As pressure built up at the forward end, most likely due to burning at the forward face, the cartridge was forced at high pressure against the aft closure insulation, thus causing the indentation.

In summary, the following facts are known:

- the igniter functioned as designed.
- the 230,000 psi/sec rate of pressure rise was caused by unplanned exposure of additional propellant burning surface (~130 in.^{2}) a temporarily plugged nozzle, or a temporary plugged pressure tap.
- the 17.5-in.-dia indentation in the aft closure insulation, ejection of the propellant cartridge, and recovery of the restrictor indicated an inadequate or non-existent bond existed between the propellant cartridge and the forward cap.

The S/N I-3 malfunction apparently was caused in incorrect installation of the propellant cartridge.

2. Remedial Action

The fired motor was returned to the processing area for disassembly and further inspection. Only minor clean-up of the insulated cap and chamber was required. The aft closure was cleaned and dimensionally inspected. Inspection results showed that the forward flange flatness and roundness were within original design tolerance. The following action was taken to repair and rehabilitate the aft closure:

- repair machining included removal of not more than 0.06 in. of material from the 24-in.-dia forward flange face to remove surface irregularities resulting from the impact and to obtain the original 125 finish for an O-ring seal.
- the exterior surface was magnetic particle inspected; no defects were found.
- damaged or unbonded insulation specimens were repaired; this included replacing the unbonded 93-104 specimen with IBT-100, removing damaged insulation at the forward face of the closure and replacing with IBT-100, and replacing damaged material and superficial surface depressions with new material.
- the pretest profiles of the repaired insulation specimens were measured.

V.D. Motor S/N I-3 Malfunction (cont)

Several changes to the motor processing procedures were made. First, 100% project surveillance of all processing operations were initiated. Second, the cartridge propellant surface was scaped prior to final assembly to remove any foreign material, glaze, or fuel rich material. Last, only 3.0-in. of SD-793 urethane potting were installed. The rehabilitated motor was identified as S/N I-3A.

VI. PHASE III - PRELIMINARY EVALUATIONS

The objective of the preliminary evaluation phase of Task I was to review the data obtained, and, on the basis of this data, select twelve materials, including V-61 and V-44 controls, for further evaluation in Tasks II and III. The selected twelve materials were to include no less than two materials each from the trowelable, castable, and sprayable groups.

A summary listing the material in their relative standing for performance (erosion), cost, density, thermal properties, and moisture absorption is presented in Figure 41. Figure 41 also shows the materials which are acceptable, marginal, or unacceptable with regard to mechanical properties, ambient pot life, and bond line tensile/shear strengths. Independent trade-off evaluations were made by personnel from Department 0720, Material Technology, Department 3810, Propellant Development, and the Project Manager. The individual material ratings, summarized in Figure 42, were based on the following characteristics:

Characteristic	Approximate Significant Weight, %
Performance (test motors)	20
Cost (raw material, processing)	25
Compatibility with propellant, liner and motor case steel	10
Physical properties	10
Mechanical properties	10
Chemical properties	10
Adhesive properties	10
Ease of repair/removal	5
	100

VI. Phase III - Preliminary Evaluations (cont)

Materials recommended and approved for further evaluation in Tasks II and III are shown in Figure 43.

The silicone rubber materials, 93-104, RTV-511, PR 1933, were eliminated from further consideration because of their poor relative erosion resistance and their poor bonding characteristics, particularly with SD850-2 liner. An unacceptable, short ambient pot life was the reason for eliminating V-61 and V-4011 from further evaluation; V-4011 also exhibited poor bond strength characteristics with SD850-2 liner. It was interesting to note that the foregoing materials (93-104, RTV-511, PR1933, V-61, and V-4011) also were the higher cost materials, as shown in Figure 41, Sheet 1, Column 2. Castable carbon was eliminated earlier in the program because an acceptable specimen could not be installed into the test motor closure. Processing complexity certainly prohibited the use of castable carbon as a large motor insulator.

Elimination of the foregoing materials left thirteen materials, plus V-44, available for selection. Pressure-cured materials, USR 3800, USR 3804, and Orco 9250 all exhibited good erosion resistance, reasonable cost, and good thermal properties. USR 3800 was selected as the best low cost pressure-cured material. Orco 9250 was the alternative material in the event that USR 3800 was unavailable. Only three trowelable materials were available; IBT-100, IBT-106, and TI-H704B. IBT-100 and IBT-106 each rated high in all characteristics evaluated. Although its erosion performance was poorer than that of the V-44 control, TI-H704B exhibited satisfactory properties in other categories to warrant its evaluation in Tasks II and III. Four castable materials were available: IBC-101, IBC-111, 40SD-80 and Avcoat 8021. IBC-111, a replacement material for castable carbon, was not included in the original twenty materials approved for Task I evaluation; as a result, thermal property data were not obtained. However, a good performance relative low cost, and properties similarity to IBC-101 indicated IBC-111 was worth further evaluation. Avcoat 8021 was not selected because the supplier would not furnish the material in the uncured condition as would be required for the Task II demonstration. The sprayable materials selected were IBS-107, IBS-109, and Avcoat II. IBS-108 was not selected because of its close chemical similarity to IBS-109. Avcoat II exhibited only fair erosion performance, but showed good density and thermal properties at relatively low cost.

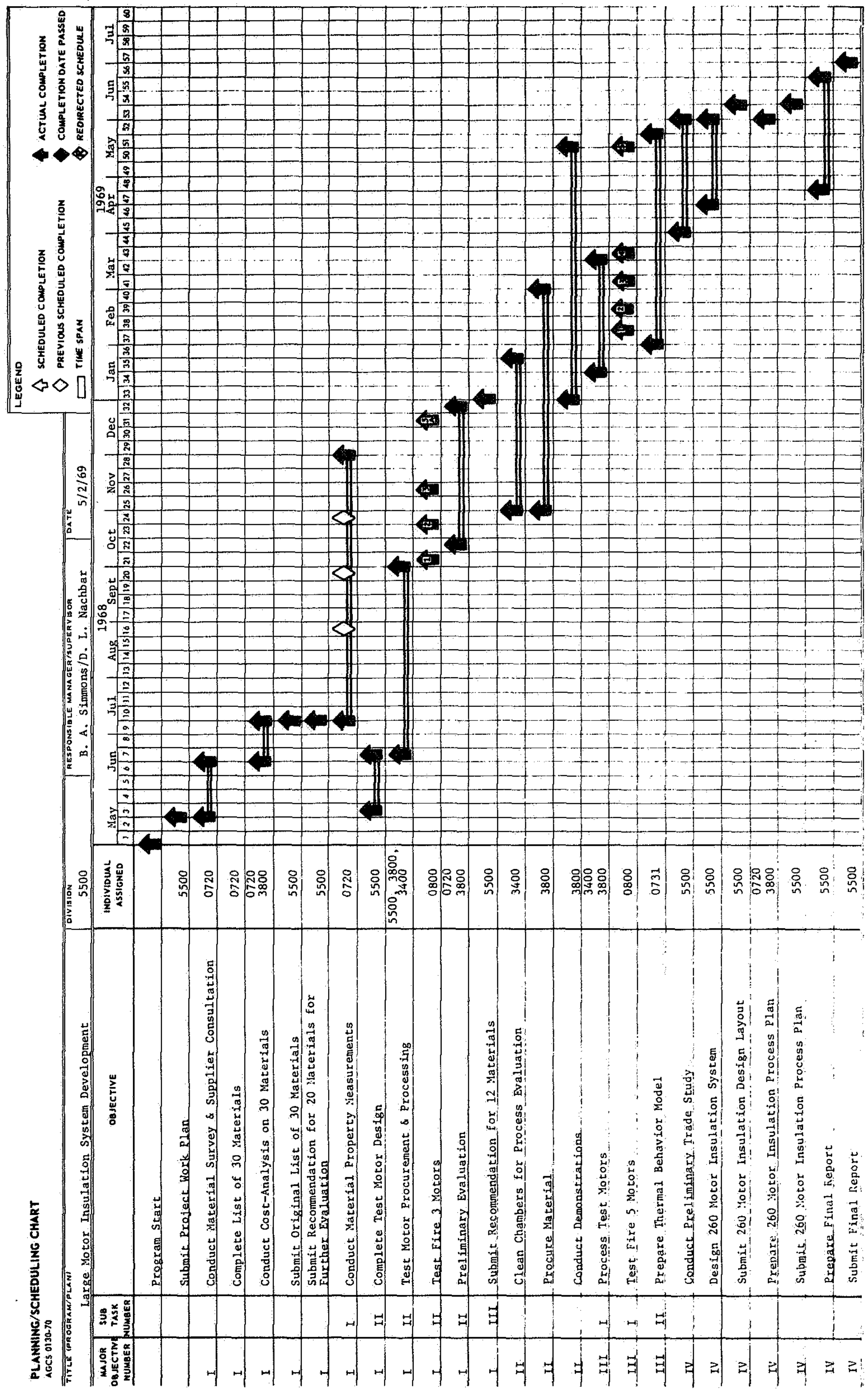
Figure 44 is a brief Task II and III material demonstration and performance evaluation plan. V-44 will be included as a control in each of the five motor tests, but will not be demonstrated in Task II. USR-3800, which rated high in performance, cost, and thermal properties, will be evaluated in one of the Task III motor tests, but as a pressure-cured material, will not be demonstrated in Task II.

VI. Phase III - Preliminary Evaluations (cont)

IBT-100 and IBT-106 will be included in one of the Task III motor tests and will be demonstrated primarily as a forward/aft head insulator in Task II. TI-H704B will be tested in Task III and demonstrated as a sidewall-head insulator in Task II.

IBC-111, IBC-101, and 40SD-80 will be included in the Task II motor tests, but only IBC-111 and 40SD-80 will be demonstrated in Task II. Bottom-casting of IBC-101 was demonstrated previously in the fabrication of inert slivers for Motor 260-SL-3.

IBS-107 and IBS-109 will be tested in Task III and will be demonstrated for both sidewall and propellant boot applications in Task II. Avcoat II will be tested in Task III and demonstrated in Task II as a sidewall insulator.



Contract Progress Schedule

Figure 1

1. Report AFRPL-TR-64-167, Vol. 1, "156-In.-Dia Motor Jet Tab TVC Program," LPC, 29 January 1965.

2. Report NASA-CR-72228, 260-SL-3 Motor Program, Vol. 1: "260-SL-3 Motor Internal Insulation System," AGC, 28 April 1967.

3. Report NASA-CR-54930, 260-IN.-Dia Motor Feasibility Demonstration Program, Vol. IV: "260-SL Motor Internal Insulation System," AGC, 8 April 1966.

4. Report AFRPL-TR-67-104, W. Bradley, "Investigation and Evaluation of Motor Insulation for Multiple Restart Application," Second Phase Report, AGC, April 1967.

5. Report No. 0314-3, W. P. Whelan, Jr., et al, "Improved Insulators for Rocket Motors," Quarterly Progress Report, U.S. Rubber Co., Contract NOw 66-0314-C, June 1966.

6. Contract NAS3-10283, "Design Criteria Monograph for Solid Rocket Motor Insulation," AGC, November 30, 1967.

7. NASA Technical Memorandum X-1277, "Casting and Spraying Techniques for Fabricating Filled Elastomeric Ablation Materials," R. C. Clark and R. T. Magee, Langley Research Center, September 1966.

8. Technical Note No. RPL-TDR-64-58, "260-In. Motor Demonstration and 156-in. Motor Nozzle Test Program," Thiokol Chemical Corp., 31 March 1964.

9. Report AFRPL-TR-65-4, "156-In.-Dia Motor Movable Nozzle Program, Vol. II - Subscale Motor Development," Thiokol Chemical Corp., 20 August 1965.

10. Report AFRPL-TR-66-109, "156-In.-Diameter Motor Liquid Injection TVC Program, Vol. II - Test Results, Motor 156-5," Lockheed Propulsion Co., July 1966.

11. Report No. AFRPL-TR-65-108, "156-In.-Dia Motor Jet Tab TVC Program," Lockheed Propulsion Co., July 1965.

12. Report No. AFRPL-TR-65-212, "156-In.-Dia Motor Jet Tab TVC Program," Lockheed Propulsion Co., December 1965.

13. Report No. AFRPL-TR-64-147, "Final Report, 156-In.-Dia Motor Jet Tab TVC Program," January 1965.

14. Report ER-UTC-65-99, Test Evaluation Report (Ground Test), U.A. 1205-15 United Technology Center, 15 June 1965.

Reference List of Reports Reviewed
on Large Rocket Motor Insulation

Figure 2, Sheet 1 of 2

15. Report No. RTD-PBR-63-2, "Research, Design, and Demonstration of Advanced Components for Large Solid-Propellant Motors," United Technology Center, May 1962.

16. "UTC Reliability and Quality Assurance Program Status Report," Quarterly Report No. 13, Contract AF 04(695)-156, United Technology Center, October - December 1965.

17. "260-SL Subscale Nozzle Verification Program," Contract NAS3-6285, Thiokol Chemical Corp., January 1966.

18. Report BSD-TR-66-207, Final Report, "High Performance Large Motor Demonstration Test Firing Program," Thiokol Chemical Corp., August 1966.

19. Report No. AFRPL-TR-66-331, "156-In. Fiberglass Case LITVC Motor Program," Thiokol Chemical Corp., January 1967.

20. Report AFRPL-TR-65-2, "260-In. Motor Demonstration and 156-In. Motor Nozzle Test Program," Thiokol Chemical Corp., 31 December 1964.

21. Report AFRPL-TR-67-287, "Investigation and Evaluation of Motor Insulation for Multiple Restart Application," Aerojet-General Corporation, November 1967.

Reference List of Reports Reviewed
on Large Rocket Motor Insulation

Figure 2, Sheet 2 of 2

AEROJET-GENERAL CORPORATION

SACRAMENTO CALIFORNIA

SACRAMENTO PLANT

Gentlemen:

The Aerojet-General Corporation has recently been awarded a contract entitled "Development of Cost-Optimized Insulation System for Use in Large Solid Rocket Motors", Contract NAS 3-11224. The initial phase of this contract is to conduct a literature and supplier survey to investigate potential candidate insulation materials applicable to large solid propellant motor cases. We would like to receive up-to-date information on the availability, cost and properties of your ______________________________ material(s), selected as tentative candidate(s) for evaluation in this program and also on other materials you may have that are suitable for this application. In order to evaluate the applicability of the available insulation materials, NASA has submitted the following directives as a guideline:

1. Material Categories

The types of materials to be considered include the following categories:

a. Chemical Groups

(1) Synthetic rubber and SR/filler combinations.

(2) Phenolic/filler, phenolic/NR/filler, and phenolic/ SR/filler combinations

b. Physical Groups

(1) Pressure cured components secondarily bonded into place.

(2) Ambient or vacuum cast components secondarily bonded into place.

(3) Room or elevated temperature cured materials troweled or cast into place.

(4) Room or elevated temperature cured materials sprayed into place.

Sample Letter Distributed to Insulation Suppliers

Figure 3, Sheet 1 of 3

Primary emphasis is to be placed on the investigation of trowelable, castable, and sprayable materials, preferably materials that can be processed at the motor processing facility.

2. Material Requirements

The specific requirements imposed on the insulation materials are as follows:

a. The material must have no unreliable usage history in solid rocket motors.

b. The supplier must be able to manufacture the materials in quantities necessary for large solid motor applications without extensive facility modifications. Assumed motor production rates shall be four units per year.

c. The supplier's quality control capability must be adequate for the intended use of the material.

On the basis of the assumed motor production rate of four units per year, it is estimated that as much as 25,000 lbs of material may be required per quarter year with a total of 100,000 lbs per year providing a single material is selected for insulation of all parts of the motor case. However, materials available in smaller quantities also will be considered as one material may be selected for insulation of the sidewall, another material for insulation of the forward and aft end of the motor case and a third material for the boots. The selection of candidate materials of the various categories, as outlined in the NASA directive, will be based on a number of factors of different significance values. The essential data to be considered are as follows:

Availability: 100,000 lbs per year (25,000 lbs per 3 months)
25,000 lbs per year (5,000 lbs per 3 months)
10,000 lbs per year (2,000 lbs per 3 months)

Delivery Time: Weeks, Days

Raw Material Cost: \$/lb for quantities 25,000; 5,000; 2,000; 200 lbs.

Processing Characteristics: Curing condition (time, temperature, pressure) Also, viscosity and potlife for the castable, trowelable and sprayable materials.

Mechanical Properties: Tensile strength, elongation, modulus, hardness.

Physical Properties: Density, thermal conductivity, specific heat, water absorption.

Bonding to Motor Case and other insulation materials: Primer-adhesive system recommended, shear and peel strength data.

Sample Letter Distributed to Insulation Suppliers

Figure 3, Sheet 2 of 3

Ablative Properties: Ablation and erosion rates in oxyacetylene torch and plasma arc tests, subscale and/or full scale motor evaluations.

Use History: Rocket motors in which the material is or has been used or evaluated. (Reference to reports.)

We would appreciate receiving data on your materials as outlined in the directives, as much of the property data as are currently available, and other information that may be of significance, as soon as possible and no later than June 5, 1968. Test methods should be included along with the property data. The materials are to be identified by trade name or designation, basic binder structure and basic filler ingredient(s). Applicable specifications also should be listed.

AEROJET-GENERAL CORPORATION
P.O. Box 15847
Sacramento, California 95813
A. A. Stenersen
A. A. Stenersen
Dept. 0726/Bldg. 2015
Telephone: 355-6061, Area Code 916

Sample Letter Distributed to Insulation Suppliers

Figure 3, Sheet 3 of 3

Pressure-Cured Group	Chemical Group (Elastomer)	Pigment Filler	Fiber Filler	Supplier
NBR[1] Class				
Gen-Gard V-44 (Control)	NBR	Silica	Asbestos	General Tire & Rubber Co.
Hitco 6520	NBR	Silica	Asbestos	H.I. Thompson Fiberglass Co.
Orco 9250	NBR	Silica	Asbestos	Ohio Rubber Co.
5031-1	NBR	Silica	Asbestos	West American Rubber Co.
EPR Class				
USR 3804	Ethylene-Propylene	Silica	Asbestos	Uniroyal, Inc.
Gen-Gard 4010	Ethylene-Propylene		Asbestos	General Tire & Rubber Co.
Butyl Class				
SMR-81-8	Butyl	Silica	Asbestos	West American Rubber Co.
NBR-Phenolic Class				
USR 3800	NBR-Phenolic	Boric Acid		Uniroyal, Inc.
N-356	NBR-Phenolic	Inorganic Hydrate		B. F. Goodrich Co.
SBR[2]-Phenolic Class				
Gen-Gard V-62	SBR-Phenolic	Silica		General Tire & Rubber Co.
Carborazole 10	Phenolic/Carborazole	Cork		Fiberite Corp.
Carborazole 18	Phenolic/Carborazole		Silica Tape	Fiberite Corp.
Carborazole 26	Phenolic/Carborazole		Silica Fabric	Fiberite Corp.

(1) Acrylonitrile-butadiene rubber
(2) Styrene-butadiene rubber

Large Rocket Motor Case Insulation Materials Recommended by Suppliers

Figure 4, Sheet 1 of 5

Pressure-Cured Group	Chemical Group (Elastomer)	Pigment Filler	Fiber Filler	Supplier
Phenolic Class				
FM 5272	Phenolic		Crepe Paper	U.S. Polymeric
Isoprene Class				
LPL 4B	Polyisoprene/ NBR	Carbon Black	Asbestos	Lockheed Propulsion Co.
Silicone Class				
S-2048	Phenyl-Methyl Silicone Rubber			Dow Corning Corp.
X-30-724	Phenyl-Methyl Silicone Rubber			Dow Corning Corp.
SE-557	Silicone Rubber			General Electric Co.
K-1213	Silicone Rubber			Union Carbide
K-1255	Silicone Rubber			Union Carbide
K-1305W	Silicone Rubber			Union Carbide
Epoxy Class				
Guardian	Modified Epoxy		Asbestos	Atlantic Research Corp.
Trowelable Group				
Epoxy-Polysulfide Class				
Gen-Gard V-61 (Control)	Epoxy-Polysulfide NBR		Asbestos	General Tire & Rubber Co.

Large Rocket Motor Case Insulation Materials Recommended by Suppliers

Figure 4, Sheet 2 of 5

Trowelable Group	Chemical Group (Elastomer)	Pigment Filler	Fiber Filler	Supplier
PBAN[(1)] Epoxy Class				
IBT-100	PBAN-Epoxy	Sb_2O_3-Carbon Black	Asbestos	Aerojet-General Corp.
IBT-106	PBAN-Epoxy	Sb_2O_3-Carbon Black	Asbestos	Aerojet-General Corp.
PBAA[(2)] Class				
LPL-44	PBAA		Asbestos	Lockheed Propulsion Co.
TI-H704B	PBAA	Carbon Black	Asbestos	Thiokol Chemical Co.
Gen-Gard 4011	Hydroxyl-Terminated Polybutadiene		Asbestos	General Tire & Rubber Co.
Silicone Class				
93-083	Silicone Rubber			Dow Corning Corp.
TBS-542	Silicone Rubber			General Electric Co.
PR-1955	Silicone Rubber			Products Research & Chemical Corp.

(1) Terpolymer of polybutadiene, acrylonitrile and acrylic acid
(2) Polybutadiene-acrylic acid copolymer

Large Rocket Motor Case Insulation Materials Recommended by Suppliers

Figure 4, Sheet 3 of 5

Castable Group	Chemical Group (Elastomer)	Pigment Filler	Fiber Filler	Supplier
PBAN-Epoxy Class				
IBC-101	PBAN-Epoxy	Sb_2O_3-Carbon Black	Asbestos	Aerojet-General Corp.
IBC-111	PBAN-Epoxy		Refrasil	Aerojet-General Corp.
Urethane Class				
40 SA 2	Polyurethane		Silica	American Poly-Therm Co.
40 SA 40	Polyurethane		Silica	American Poly-Therm Co.
40 SD 80	Polyurethane			American Poly-Therm Co.
Silicone Class				
93-073	Silicone Rubber			Dow Corning Corp.
93-104	Silicone Rubber			Dow Corning Corp.
RTV-511	Silicone Rubber			General Electric Corp.
Carbon Class				
Castable Carbon	Furanepolymer	Carbon		Atlantic Research Corp.
Epoxy-Polyamide Class				
Avcoat 8021	Epoxy-Polyamide			Avco Corp.

Large Rocket Motor Case Insulation Materials Recommended by Suppliers

Figure 4, Sheet 4 of 5

Sprayable Group	Chemical Group (Elastomer)	Pigment Filler	Fiber Filler	Supplier
PBAN-Epoxy Class				
IBS-105	PBAN-Epoxy	Sb_2O_3-Carbon Black	Asbestos	Aerojet-General Corp.
IBS-108	PBAN-Epoxy	Sb_2O_3-Carbon Black	Asbestos	Aerojet-General Corp.
IBS-109	PBAN-Epoxy	Sb_2O_3-Carbon Black	Asbestos	Aerojet-General Corp.
CTPB Class				
IBS-107	Carboxy-terminated Polybutadiene	Sb_2O_3	Silica	Aerojet-General Corp.
Epoxy-Polyamide Class				
Avcoat II	Epoxy-Polyamide			AVCO Corp.
Silicone Class				
PR-1933	Silicone Rubber			Product Research & Chemical Corp.

Large Rocket Motor Case Insulation Materials Recommended by Suppliers

Figure 4, Sheet 5 of 5

Material	Specific Gravity, GM/cc	Thermal Conduct. Btu-in/hr-ft²-°F	Specific Heat @ 250°F cal/g.°C	Moisture Absorption, %	Tensile Strength psi	Elongation at Max. Tensile Strength, %	Modulus psi	Shore Hardness	Ablation Rate in Oxy-Acetylene Torch Test, mils/sec: 100 Btu/ft²-sec	Ablation Rate in Oxy-Acetylene Torch Test, mils/sec: 225 Btu/ft²-sec	Ablation Rate in Plasma Arc Test, mils/sec: 50 Btu/ft²sec	Ablation Rate in Plasma Arc Test, mils/sec: 100 Btu/ft²sec	Ablation Rate in Plasma Arc Test, mils/sec: 225 Btu/ft²-sec	Raw Material Cost, $/lb: 2000 lb	Raw Material Cost, $/lb: 5000 lb	Raw Material Cost, $/lb: 25,000 lb	Del. Time, Weeks	Typical Curing Cond. For 0.25-in. Thick Slab: Temp. °F	Typical Curing Cond. For 0.25-in. Thick Slab: Pressure, psi	Typical Curing Cond. For 0.25-in. Thick Slab: Time hr.	Mooney Visc. @ 212°F	Mooney Scorch, min.
Pressure-Cured Group																						
V-44	1.269	2.266	0.433	0.016	1331	430	--	85	1.80	--	1.30	2.85	3.59	3.19	3.19	3.19	13	310	100-200	1	90	5
HITCO 6520	1.28	--	--	--	2500	550	--	70	1.30	--	--	--	--	1.50	1.50	1.50	8-10	310	100-200	1	--	--
ORCO 9250	1.28	1.47	0.46	--	1425/1700	650/700	--	84	1.30	--	--	--	--	1.46	1.46	1.46	4-6	310	100-200	1	60	21
5031-1	1.27	--	0.36	9.092	800/1250	175/475	--	80	2.4 0.8*	--	--	--	--	1.68	1.26	1.24	3-6	310	100-200	1	72	9
USR 3804	1.119	--	0.418	--	1200	400	--	--	--	--	1.30	2.19	3.50	1.80	1.80	1.40	8-10	310	100-200	1	--	--
4010	1.09	1.188	0.493	--	2003	797	5300	--	1.0	--	1.33	2.19	3.58	3.03	3.03	3.03	13	300	100-200	1	53	5
SMR 81-8	1.35	1.770	0.478	--	934	350	2200	--	--	--	1.69	2.19	4.25	1.80	1.80	1.40	8-10	310	100-200	1	68	12.5
USR 3800	1.15	1.230	0.514	--	1200	325	--	--	--	--	1.10	1.90	3.08	1.80	1.80	1.40	8-10	310	100-200	1	--	--
N-356	1.204	1.740	0.511	--	800	200	--	45 Shore D	--	2.0	0.71	1.59	3.02	3.11	2.61	2.61	8-12	310	100-200	1	--	--
V-62	1.063	1.204	0.454	--	675	740	1789	84	0.4	--	0.49	2.05	2.99	3.40	3.40	3.40	13	300	100-200	1	--	--
Carborazole 10	0.64	0.6	0.5	--	400	40	--	--	--	--	--	--	--	3.54	3.54	3.54	10	300	150	1	--	--
Carborazole 18	0.64	0.85	0.3	--	400/900	2/5	--	--	--	--	--	--	--	3.71	3.71	3.71	10	300	150	1	--	--
Carborazole 26	1.28	1.3	0.28	--	3000/6000	0.6/25	--	--	--	--	--	--	--	5.94	5.94	5.94	10	300	150	1	--	--
FM 5272	1.34	--	--	--	7410	0.9	9×10^5	--	--	--	--	--	--	2.00	2.00	2.00	3	--	--	--	--	--
LPL-4B	1.30	--	0.31	--	400/700	50	--	39/55 Shore D	--	--	--	--	--	2.56	2.50	2.46	12	320	250	1	--	--
S-2048	1.30	1.76	0.29	--	850	300	--	59	--	--	--	--	--	3.50	3.50	3.25	4-6	480	--	4	--	--
X-30-724	1.57	--	--	--	840	140	--	83	--	--	--	--	--	3.50	3.50	3.25	4-6	480	--	4	--	--
SE-557	1.88	--	--	--	1400	600	--	--	--	--	--	--	2.0/ 3.2	3.38	3.38	3.36	4-6	400	--	4	--	--
K-1213	1.16	--	--	--	1100	850	--	30	--	--	--	--	--	2.80	2.80	2.80	--	400	--	4	--	--
K-1215	1.23	--	--	--	1400	700	--	44	--	--	--	--	--	3.25	3.20	3.20	--	350	--	4	--	--
K-1305W	1.16	--	--	--	1050	400	--	47	--	--	--	--	--	2.85	2.80	2.80	--	340	--	20 (min.)	--	--
Guardian	--	--	--	--	--	--	--	--	--	--	--	--	--	1.75(2)	1.75(2)	1.75(2)	--	--	--	--	--	--

*UTC Data

Summary of Insulation Material Property Data Received from Suppliers

Figure 5, Sheet 1 of 3

Material	Specific Gravity, GM/cc	Thermal Conduct. Btu-in/hr-ft²-°F	Specific Heat @ 250°F cal/g,°C	Moisture Absorption, %	Tensile Strength, psi	Elongation at Max. Tensile Strength, %	Modulus, psi	Shore Hardness	Ablation Rate in Oxy-Acetylene Torch Test mils/sec: 100 Btu ft²-sec	Ablation Rate in Oxy-Acetylene Torch Test mils/sec: 225 Btu ft²-sec	Ablation Rate in Plasma Arc Test, mils/sec: 50 Btu ft²-sec	Ablation Rate in Plasma Arc Test, mils/sec: 100 Btu ft²-sec	Ablation Rate in Plasma Arc Test, mils/sec: 225 Btu ft²-sec	Raw Material Cost, $/lb: 2000 lb	Raw Material Cost, $/lb: 5000 lb	Raw Material Cost, $/lb: 25,000 lb	Del. Time, Weeks	Viscosity @ 77°F Centipose	Pot Life @ 77°F hr	Curing Conditions Temp, °F	Curing Conditions Time, hr
Trowelable																					
V-61	1.308	1.443	0.433	—	900	2	—	20	1.4	—	1.91	3.65	3.98	4.45	4.15	3.48	13	—	0.5	75/120	144/6
IBT-100	1.39	1.618	0.382	0.5	866	69	3900	—	—	—	1.29	2.60	3.65	0.65(2)	0.65(2)	0.65(2)	8-12	—	4-6	135	48
IBT-106	1.40	—	—	0.5	1640	69	11,500	—	—	—	—	—	—	0.60(2)	0.60(2)	0.57(2)	8-12	—	8-10	135	48
LPL-44	1.30	—	0.34	—	884	38	—	85	—	—	—	—	—	4.63	3.48	2.78	8	—	12	77/160	—
TI-H704B	1.30	—	0.325	—	175	1	—	—	—	—	—	—	—	2.02	1.90	1.87	6-8	—	5-6	135	72/120
4011	1.10	—	—	—	975	40	—	82	1.7	—	—	—	—	6.25	6.25	6.25	6	—	2	75	24/120
93-083	1.75	4.1	—	—	275	75	—	65	—	—	—	—	—	8.00	8.00	6.00	4-6	—	2	77	24
TBS-542	1.34	—	0.36	—	450	50	—	—	—	—	—	—	—	12.00	12.00	7.00	4-6	80,000	2	77	144
PR-1955	1.40	—	—	—	300	200	—	50	—	—	—	—	—	6.46	6.40	6.36	4-5	13,000	2	75/120	24/4
Castable																					
IBC-101	1.320	—	—	—	484	88	905	—	—	—	—	—	2.2/	0.67(2)	0.64(2)	0.64(2)	8-12	3,000/ 6,000	6-8	135	4
IBC-111	1.389	—	—	—	521	93	1245	69	—	—	—	—	3.0	1.50(2)	1.50(2)	1.50(2)	8-12	1500/ 3000	12	135	8-12
AVCOAT 8021	—	—	0.4	—	2940	134	—	—	—	—	—	—	—	2.16	2.16	1.89	—	—	—	200	—
40-SA-2	1.327	1.360	0.382	—	1100	130	5000	—	—	—	1.20	2.44	5.97	8.25	7.75	6.50	4-6	—	0.5-1	180	4-8
40-SA-40	1.338	1.930	0.451	—	1126	133	5261	—	—	—	1.35	3.56	5.44	8.25	7.75	6.50	4-6	—	0.5-1	180	4-8
40-SA-80	1.15	—	—	—	800	180	—	—	—	—	—	—	—	4.00	4.00	2.80	4-6	800/ 1200	1-2	77/240	24/4
93-073	1.75	4.1	—	—	275	75	—	65	—	—	—	—	—	8.00	8.00	6.00	4-6	1.1×10^6	2	77	24
93-104	1.44	2.42	—	—	275	75	—	65	—	—	—	—	2.3	8.00	8.00	6.00	4-6	1.1×10^6	—	77	24
RTV-511	1.20	—	—	—	350	180	—	45	—	—	—	—	—	5.55	5.55	5.55	4-6	200,000	4-8	77	24

Summary of Insulation Material Property Data Received from Suppliers

Figure 5, Sheet 2 of 3

Material	Specific Gravity, GM/cc	Thermal Conduct. Btu-in./hr-ft^2-°F	Specific Heat @ 250°F cal/g, °C	Moisture Absorption, %	Tensile Strength psi	Elongation at Max. Tensile Strength %	Modulus, psi	Shore Hardness	Ablation Rate in Oxy-Acetylene Torch Test mils/sec: 100 Btu/ft^2-sec	Ablation Rate in Oxy-Acetylene Torch Test mils/sec: 225 Btu/ft^2-sec	Ablation Rate in Plasma Arc Test, mils/sec: 50 Btu/ft^2-sec	Ablation Rate in Plasma Arc Test, mils/sec: 100 Btu/ft^2-sec	Ablation Rate in Plasma Arc Test, mils/sec: 225 Btu/ft^2-sec	Raw Material Cost $/lb: 2000 lb	Raw Material Cost $/lb: 5000 lb	Raw Material Cost $/lb: 25,000 lb	Del. Time, Weeks	Viscosity @ 77°F Centipose	Pot Life @ 77°F hr.	Curing Conditions: Temp, °F	Curing Conditions: Time, hr
Sprayable																					
IBS-105	1.30	--	--	0.5	54	143	119	--	--	--	--	--	--	0.76(2)	0.76(2)	0.69(2)	8-12	3000-6000	6-8	135	48
IBS-107	1.240	1.920	0.34	0.5	770	26	6552	--	--	--	--	--	--	1.62(2)	1.60(2)	1.60(2)	8-12	1000-3000	1-3	135	12
IBS-108	1.208	--	--	0.5	--	--	--	--	--	--	--	--	--	0.73(2)	0.67(2)	0.67(2)	8-12	3000-6000	6-8	135	48
IBS-109	1.237	--	--	0.5	--	--	--	--	--	--	1.0	2.9	--	0.72(2)	0.66(2)	0.66(2)	8-12	3000-6000	6-8	135	48
AVCOAT II	1.02	--	0.34	--	2000	23	--	40 Shore D	--	--	--	--	--	1.65	1.65	1.55	12-24	15,000	--	77	16
PR-1933	1.45	1.44	0.29	--	550	250	--	35 Rex	--	--	--	--	--	5.17	5.17	5.00	3-4	250,000-800,000	0.5-2	75/120	24/4
Castable Carbon	--	--	--	--	--	--	--	--	--	--	--	--	--	0.20(3)	0.20(3)	0.20(3)	4-6	--	--	--	--

Summary of Insulation Material Property Data Received from Suppliers

Figure 5, Sheet 3 of 3

Pressure-Cured Group	Rocket Motor Applications: Large Rocket Motors	Rocket Motor Applications: Smaller Motors	Performance Characteristics
Gen-Gard V-44 (Control)	Used in the 100-, 120-, 156-, and 260-in.-dia. motors (U.T.C., Lockheed, Thiokol, Aerojet)	Polaris A3 Minuteman Wing II	Excellent performance reliability and reproducibility.
Hitco 6520	Forward dome and low erosion areas of L-71 (156-in.-dia.) motor (Lockheed).		Good performance.
Orco 9250	120-in.-dia. SRM for Titan III-C.		Good performance.
5031-1	Aft dome insulation in L-71 (156-in.-dia.) motor (lockheed): 120-in.-dia SRM for Titan III-C.		Good performance.
USR-3804		Genie Motors	Low ablation rates.
Gen-Gard 4010		Genie Motors	Low ablation rates.
SRM-81-8		Used in a number of small motors including Sparrow and ZAP	Good performance at low gas velocities.
USR-3800		Polaris A3, Genie Motors	Good performance at high and low gas velocities.
N-356		Genie Motors	Good performance.
Gen-Gard V-62		74-in.-dia Upper Stage motor and Genie Motors	Good performance.

Use History of Supplier Recommended Insulation Materials

Figure 6, Sheet 1 of 4

Pressure-Cured Group	Rocket Motor Applications: Large Rocket Motors	Rocket Motor Applications: Smaller Motors	Performance Characteristics
Carborazole 10			
Carborazole 18			
Carborazole 26			
FM 5272		Evaluated in test motors for use in the 260-in.-dia nozzle (Thiokol) and for use in the Nomad motor.	Low ablation rates.
LPL 4B		Subscale motors (156-in.-dia program).	Good overall performance.
S-2048		Subscale motors	Good ablative properties.
X-30-724			
SE-557		Subscale motors	Good ablative properties.
K-1213			
K-1255			
K-1305W		Subscale motors	Good ablative properties.
Guardian		Subscale motors	Good performance.

Use History of Supplier Recommended Insulation Materials

Trowelable Group	Rocket Motor Applications: Large Rocket Motors	Rocket Motor Applications: Smaller Motors	Performance Characteristics
Gen-Gard V-61	Used as a repair and joint sealant material in the 120- and 260-in.-dia motors.		Good performance in high and low gas velocity areas.
IBT-100	Used as nozzle shell insulation in the 260-SL-3 motor.	Polaris test motor Genie motors.	Low ablation rates in high gas velocity areas.
IBT-106		Subscale 44-in.-dia motor (260-in.-dia. rocket motor program) AGC. Self-Eject Launch Technology Program Subscale test motors, AGC	Good performance.
LPL-44	Forward and aft dome insulation in (1-72) (156-in.-dia) motor (Lockheed)		Good performance.
TI-H704B		Subscale 66-SS-2 and 66-SS-3 motors (156-in.-dia program) (Thiokol).	Good performance.
93-083			
TBS-542			
PR-1955			

Use History of Supplier Recommended Insulation Materials

Figure 6, Sheet 3 of 4

Castable Group	Rocket Motor Applications: Large Rocket Motors	Rocket Motor Applications: Smaller Motors	Performance Characteristics
IBC-101	Used as inert slivers in the 260-SL-3 motor		Good performance.
40SA-2		Genie motors	Good performance.
40SA-40		Hawk and Genie motors	Good performance in low gas velocity regions.
40SD-80			
93-073			
93-104			
RTV-511		Used as base heat insulation in Polaris A3 motor	Good performance.
Castable Carbon		Nomad Test Motors	Low ablation rate in high gas velocity regions.
Avcoat 8021			
Sprayable Group			
IBS-105			
IBS-108		Diameter wall insulation in 2.75 FFAR motor	Good performance.
IBS-109		Aft end insulation in 2.75 FFAR motor	Good performance.
IBS-107		Evaluated in Advanced Sparrow motors	Good performance.
Avcoat II		External insulation of Minuteman motors	Good performance at low heat flux levels.
PR 1933			

Use History of Supplier Recommended Insulation Materials

Figure 6, Sheet 4 of 4

Material Designation	Supplier	Basic Binder	Basic Filler	Physical Group
Gen-Gard V44 (Control)	General Tire & Rubber Co. Akron, Ohio	Acrylonitrile-butadiene	Asbestos-Silica	Pressure Cure
5031-1	West American Rubber Co.	Acrylonitrile-butadiene	Asbestos	Pressure Cure
6520	H. I. Thompson Co. Gardena, Calif.	Acrylonitrile-butadiene	Silica	Pressure Cure
ORCO 9250	Ohio Rubber Co.	Acrylonitrile-butadiene	Asbestos-Silica	Pressure Cure
USR 3804	U. S. Rubber Co. Mishewaka, Indiana	Ethylene-propylene rubber	Asbestos	Pressure Cure
Gen-Gard V4010	General Tire & Rubber Co. Akron, Ohio	Ethylene-propylene rubber	Asbestos	Pressure Cure
Gen-Gard V62	General Tire & Rubber Co. Akron, Ohio	Styrene-butadiene rubber	Asbestos	Pressure Cure
LPE-2	Lockheed Company Redlands, Calif.	Polyisoprene-butadiene	Asbestos	Pressure Cure
N-356	B. F. Goodrich Co. Akron, Ohio	Phenolic-Acrylonitrile-butadiene	Inorganic Hydrate	Pressure Cure
SE 557	General Electric Co. Waterford, N. Y.	Silicone rubber	Silica	Pressure Cure
S-2048	Dow Corning Corp. Midland, Mich.	Silicone rubber	Silica	Pressure Cure

Intermediate List of 30 Insulation Materials Applicable to Large Rocket Motors

Figure 7, Sheet 1 of 3

Material Designation	Supplier	Basic Binder	Basic Filler	Physical Group
X-30742	Dow Corning Corp. Midland, Mich.	Silicone rubber	Silica	Pressure Cure
USR 3800	U. S. Rubber Co. Mishewaka, Indiana	Phenolic-Acrylo-nitrile-butadiene	Boric Acid	Pressure Cure
SMR 81-8	West American Rubber Co. Anaheim, Calif.	Butyl rubber	Asbestos-Silica	Pressure Cure
Gen-Gard V61	General Tire & Rubber Co. Akron, Ohio	Epoxy-Polysulfide Acrylonitrile-butadiene	Asbestos	Troweling
LPC-31	Lockheed Company Redlands, Calif.	Polybutadiene Acrylonitrile-Acrylic Acid Terpolymer	Asbestos	Troweling
TI-H704B	Thiokol Chemical Co. Brigham City, Utah	Polybutadiene Acrylonitrile-Acrylic Acid Terpolymer	Asbestos	Troweling
IBT-100 (SD850-15C)	Aerojet-General Corp. Sacramento, Calif.	Polybutadiene Acrylonitrile-epoxy	Asbestos	Troweling
IBT-106	Aerojet-General Corp. Sacramento, Calif.	Polybutadiene-Acrylonitrile-epoxy	Asbestos	Troweling
93-083	Dow Corning Corp. Midland, Micn.	Silicone rubber	Silica	Troweling

Intermediate List of 30 Insulation Materials Applicable to Large Rocket Motors

Figure 7, Sheet 2 of 3

Material Designation	Supplier	Basic Binder	Basic Filler	Physical Group
40SA2	American Polytherm Co. Sacramento, Calif.	Polyurethane	Silica	Casting
40SA40	American Polytherm Co. Sacramento, Calif.	Polyurethane	Silica	Casting
IBC-101	Aerojet-General Corp. Sacramento, Calif.	Polybutadiene-Acrylonitrile-epoxy	Asbestos	Casting
93-073	Dow Corning Corp. Midland, Mich.	Silicone rubber	Silica	Casting
SD 878-2	Aerojet-General Corp. Sacramento, Calif.	Polybutadiene-Acrylonitrile & Terpolymer of Polybutadiene, Acrylonitrile & Acrylic Acid	Antimony Oxide Potassium Titanate	Spraying
IBS-108	Aerojet-General Corp. Sacramento, Calif.	Polybutadiene-Acrylonitrile	Asbestos	Spraying
IBS-105	Aerojet-General Corp. Sacramento, Calif.	Polybutadiene-Acrylonitrile-epoxy	Asbestos	Spraying
RTV 511	General Electric Co. Waterford, N. Y.	Silicone rubber	Silica	Spraying
NRL 1126	Insulation Technology,Inc. Sacramento, Calif.	Phenolic	Refractory Powder	Spraying
AVCOAT II	AVCO, Corp. Lowell, Mass.	Epoxy-polyamide	Refractory Powder	Spraying

Intermediate List of 30 Insulation Materials Applicable to Large Rocket Motors

Figure 7, Sheet 3 of 3

Material	Supplier
Pressure-Cured Class (4 Materials)	
Gen-Gard V-44 (Control)	General Tire & Rubber Co.
Orco 9250	Ohio Rubber Co.
USR 3804	Uniroyal, Inc.
USR 3800	Uniroyal, Inc.
Trowelable (6 Materials)	
Gen-Gard V-61 (Control)	General Tire & Rubber Co.
IBT-100	Aerojet-General Corp.
IBT-106	Aerojet-General Corp.
LPL-44 [1]	Lockheed Propulsion Co.
TI-H704B	Thiokol Chemical Corp.
Gen-Gard 4011	General Tire & Rubber Co.
Castable (5 Materials)	
IBC-101	Aerojet-General Corp.
40 SD-80	American Poly-Therm Co.
Castable Carbon [2]	Atlantic Research Corp.
RTV-511	General Electric Corp.
Avcoat 8021	AVCO Corp.
93-104 [1]	Dow Corning Corp.
IBC-111 [2]	Aerojet-General Corp.
Sprayable (5 Materials)	
IBS-107	Aerojet-General Corp.
IBS-108	Aerojet-General Corp.

List of 20 Insulation Materials Selected for Evaluation in Task I

Figure 8, Sheet 1 of 2

Sprayable Class

	Supplier
IBS-109	Aerojet-General Corp.
Avcoat II	AVCO Corp.
PR-1933	Products Research & Chem. Corp.

1 Material could not be procured at acceptable cost to program; DC-93-104 used in place of LPL-44.

2 Could not be processed into test motor aft closure; IBC-111 used in place of castable carbon.

List of 20 Insulation Materials Selected for Evaluation in Task I

Figure 8, Sheet 2 of 2

Material	Supplier	Procurement Summary
V-44	GT&R	Available; residual from 260-SL-3 program
Orco 9250	Ohio Rubber	Purchase Order G10352; $75 for 45 lb or $1.67/lb
USR 3800	Uniroyal	Free Samples; 35 lb
USR 3804	Uniroyal	Free Sample; 35 lb
V-61	GT&R	Available; residual from 260-SL-3 program
IBT-100	AGC	Raw material; $0.65/lb
IBT-106	AGC	Raw material; $0.60/lb
LPL-44	LPC	Procurement cancelled
TI-H704B	TCC	Free Sample; 6 lb
4011	GT&R	Free Sample; 25 lb
IBC-101	AGC	Raw material available; $0.67/lb
IBC-111	AGC	Raw material available
40SD-80	American Polytherm	Purchase Order G635512; $135 for 30 lb or $4.50/lb
Castable Carbon	ATC	Purchase Order G635625; $115 for 25 lb or $4.60/lb
RTV-511	GE	Purchase Order G635367; $144 for 24 lb or $5.10/lb
Avcoat 8021	AVCO	Purchase Order G 104219; $170 for 20 lb or $8.50/lb
93-104	DC	Free Sample; 20 lb
IBS-107	AGC	Raw material available; $1.62/lb
IBS-108	AGC	Raw material available; $0.73/lb
IBS-109	AGC	Raw material available; $0.72/lb
Avcoat II	AVCO	Purchase Order G636021; $74.50 for 26.5 lb or $2.79/lb
PR 1933	PR	Purchase Order G103542; $207.78 for 34 lb or $6.15/lb

Task I Insulation Material Procurement

Figure 9

Material	Mechanical Properties @ 77°F: Tensile Strength, psi	Elongation △2 %	Elongation △3 %	Modulus, psi	Shore A Hardness	Density, gm/cc 100°F	200°F	300°F	Heat Capacity, cal/gm-°C 150°F	250°F	300°F	Thermal Diffusivity, cm²/sec 74°F	125°F	150°F	200°F	250°F	275°F	Thermal Conductivity, Btu-in/hr-ft²-°F 74°F	150°F	200°F	250°F
V-44	775	288	315	1580	73	1.296	1.204	1.206	0.407	0.443	0.445	.00145	--	.0014	--	.00135	--	1.955	2.034	--	2.118
Orco 9250	789	483	504	2141	67	1.259	1.228	1.207	0.373	0.401	0.408	.00135	--	.0013	---	.0012	--	1.942	1.886	--	1.844
USR 3800	1096	183	200	26,205	90	1.146	1.090	0.971	0.432	0.514	Melted	.00086	.00089	.00083	--	.00077	--	0.783	1.171	--	1.206
USR 3804	735	252	276	2424	79	1.199	1.166	1.126	0.375	0.418	0.432	.0016	--	.0015	--	.0015	.00151	1.686	1.927	--	2.081
V-61	1333	8.3	8.5	22,951	90	1.308	1.233	1.146	0.382	0.471	0.431	.0010	.00121	.00096	--	.00087	.00088	1.170	1.352	--	1.413
IBT-100	866	59	61	3900	90	1.390	1.351	1.319	0.324	0.367	0.388	.0013	.00118	.0013	--	.0013	--	1.529	1.675	--	1.848
IBT-106	8366	36	37	8873	89	1.423	1.374	1.356	0.356	0.403	0.425	.00115	--	.00135	--	.00145	--	1.519	1.945	--	2.310
93-104	120	26	29	1376	51	1.431	1.373	1.340	0.288	0.328	0.346	.00215	--	.0019	--	.0018	--	2.265	2.216	--	2.321
TI-H704B	123	165	184	442	31	1.334	1.293	1.251	0.364	0.410	0.428	.0026	--	.0022	--	.00175	--	3.358	3.069	--	2.654
4011	1405	38	46	5962	81	1.200	1.145	1.112	0.428	0.446	0.450	.00165	--	.00135	--	.0012	--	2.184	1.959	--	1.754
IBC-101	942	133	135	3373	81	1.329	1.283	1.111	0.363	0.396	0.414	.0012	--	.00155	--	.00145	--	1.452	2.145	--	2.050
40SD-80	865	80	83	2364	54	1.312	1.263	1.249	0.337	0.375	0.396	.0012	--	.0013	--	.00145	--	1.520	1.628	--	1.976
Castable Carbon						1.674	1.625	1.599	0.216	0.234	0.241	.0172	--	.0151	--	.0148	--	16.491	16.140	--	16.086
RTV-511	82	68	68	167	34	1.169	1.124	1.083	0.346	0.374	0.378	.00145	--	.0016	--	.0012	--	1.486	1.822	--	1.444
Avcoat 8021	3332	91	91	35,958	90	1.192	1.346	1.300	0.453	0.497	0.512	.0011	--	.00087	--	.00082	--	1.591	1.322	--	1.329
IBS-107	1112	23	36	13,534	84	1.225	1.190	1.164	0.389	0.439	0.457	.00115	--	.00125	--	.0011	--	1.366	1.698	--	1.647
IBS-108 △1	118	151	160	193	24	1.253	1.207	1.107	0.389	0.439	0.460	.00145	--	.0021	--	.00213	--	1.825	2.866	--	3.172
IBS-109	178	95	96	348	35	1.235	1.199	1.175	0.385	0.418	0.436	.0016	--	.00155	.00125	--	--	2.254	2.127	1.753	--
Avcoat II	2364	30	31	45,490	51	1.102	1.051	1.026	0.507	0.540	0.554	.00084	--	.00083	--	.00083	--	1.263	1.309	--	1.334
PR1933	291	228	228	132	21	1.416	1.346	1.300	0.320	0.360	0.371	.0017	--	.0019	.0030	--	--	1.864	2.428	3.886	--

NOTES: △1 IBS-108 synonymous with original IBS-105 identification.
△2 Strain at maximum tensile strength.
△3 Strain at break.

Property Measurement Data Summary

Figure 10, Sheet 1 of 4

	Bonding Components [2]	Bonding System Insulation to Steel [3]	Bond Line Tensile and Shear Strength: Tensile Bond Strength, psi	Type Failure, [4]	Shear Bond Strength, psi	Type Failure [4]	Working Consistency	Ambient Pot Life, hrs	Heat of Combustion cal/gm	Heat of Combustion Btu/lb
V-44	S/I/L/P	162-Y-22/Epon 948.2	155.1	P	134.4	P	Solid	----	5822	10,480
Orco 9250	S/I/L/P	162-Y-22/Epon 948.2	171.1	P	134.9	P	Solid	----	5897	10,614
USR 3800	S/I/L/P	162-Y-22/Epon 948.2	167.5	P	130.6	P	Solid	----	6474	11,653
USR 3804	S/I/L/P	162-Y-22/Epon 948.2	175.3	P	137.3	P	Solid	----	7053	12,695
V-61	S/I/L/P	162-Y-22	148.0	P	138.5	P	Paste	0.25	5441	9,794
IBT-100	S/I/P [5]	162-Y-22/Epon 948.2	166.8	P	105.0	P	Paste	16-24	6151	11,072
IBT-106	S/I/P [5]	162-Y-22/Epon 948.2	161.4	P	107.7	P	Semi-Viscous Paste	16-24	6931	12,476
93-104	S/I/L/P	162-Y-22/Epon 948.2	No measurable bond attained between insulation and liner				Fluid	2	4182	7,528
TI-H704B	S/I/L/P	162-Y-22/Epon 948.2	159.8	P	122.7	P	Paste	~12	6916	12,449
IBC-101	S/I/P [5]	162-Y-22/Epon 948.2	131.3	P	104.5	P	Fluid	12-16	7724	13,903
4011	S/I/L/P	162-Y-22/Epon 948.2	8	IL	58	IL	Paste	0.5	7199	12,958
40SD-80	S/I/L/P	162-Y-22/Epon 948.2	109.0	P	>200	P	Fluid	3	5772	10,390
RTV-511	S/I/L/P	162-Y-22/Epon 948.2	No measurable bond attained between insulation and liner				Fluid	6	5434	9,781
Avcoat 8021	S/I/L/P	162-Y-22/Epon 948.2	169.5	P	130.8	P	Solid	----	8434	15,181
IBS-107	S/I/P [5]	162-Y-22/Epon 948.2	93.3	P	102.1	P	Viscous Liquid	6	8592	15,466
IBS-108 [1]	S/I/P [5]	162-Y-22/Epon 948.2	126.6	IP	75.8	IP	Viscous Liquid	12-16	8530	15,354
IBS-109	S/I/P [5]	162-Y-22/Epon 948.2	125.2	IP	82.3	[6]	Viscous Liquid	12-16	8267	14,881
Avcoat II	S/I/L/P	162-Y-22/Epon 948.2	93.8	IL	72.6	[6]	Fluid	4	9934	17,880
PR 1933	S/I/L/P	162-Y-22/Epon 948.2	No measurable bond attained between insulation and liner				Semi-Viscous Paste	2	4412	7,941

Property Measurement Data Summary

Figure 10, Sheet 2 of 4

	Liner	Bond Strength "As Received"		Bond Strength After Drying			Bond Strength After 50% RH Storage			Bond Strength After 90% RH Storage		
		Tensile, psi	Shear, psi	Tensile, psi	Shear, psi	Weight Loss, %	Tensile, psi	Shear, psi	Weight Gain %	Tensile, psi	Shear psi	Weight Gain, %
V-44	SD850-2	155	134	96	122	2.25	138	143	1.13	162	131	2.40
Orco 9250	SD850-2	172	135	173	155	1.92	100	148	1.01	85	116	1.80
USR 3800	SD850-2	168	131	181	178	10.44	158	164	1.51	159	116	2.60
USR 3804	SD850-2	175	137	99	159	0.59	158	164	0.36	159	116	0.77
V-61	SD850-2	158	139	160	130	4.40	158	157	1.65	152	125	3.12
IBT-100	None	167	105	53 △8	52 △9	0.16	55 △9	34 △9	0.34	69 △8	48 △9	0.62
IBT-106	None	161	108	104 △9	66 △9	0.16	84 △9	92	0.39	59 △8	80	0.73
93-104	Not Tested											
TI-H704B	SD850-2	160	122	94	139	0.43	138	144	0.30	161	101	1.78
4011	Not Tested											
IBC-101	None	131	105	64	63 △9	0.14	61 △9	74 △9	0.42	83 △9	69 △9	0.84
40SD-80	SD850-2	109	262	182	127	0.47	104	157	0.49	103	210	1.03
RTV-511	Not Tested											
Avcoat 8021	SD850-2	170	131	55	199	0.60	150	179	0.94	151	144	1.63
IBS-107	None	93 △8	102 △8	73	77	0.11	85 △8	88 △8	0.32	77 △8	62 △8	0.65
IBS-108 △1	None	127 △9	71 △8 △9	63 △9	38 △9	0.29	61 △9	42 △9	0.30	56 △9	31 △9	0.60
IBS-109	None	125 △9	82 △9	86 △9	59 △9	0.44	46 △9	32 △9	0.31	74 △9	40 △9	0.60
Avcoat II	Not Tested											
PR 1933	Not Tested											
IBC-111	None	96	189	103 △8	109 △8	0.16	75	89	0.32	84 △10	103	0.68

Property Measurement Data Summary

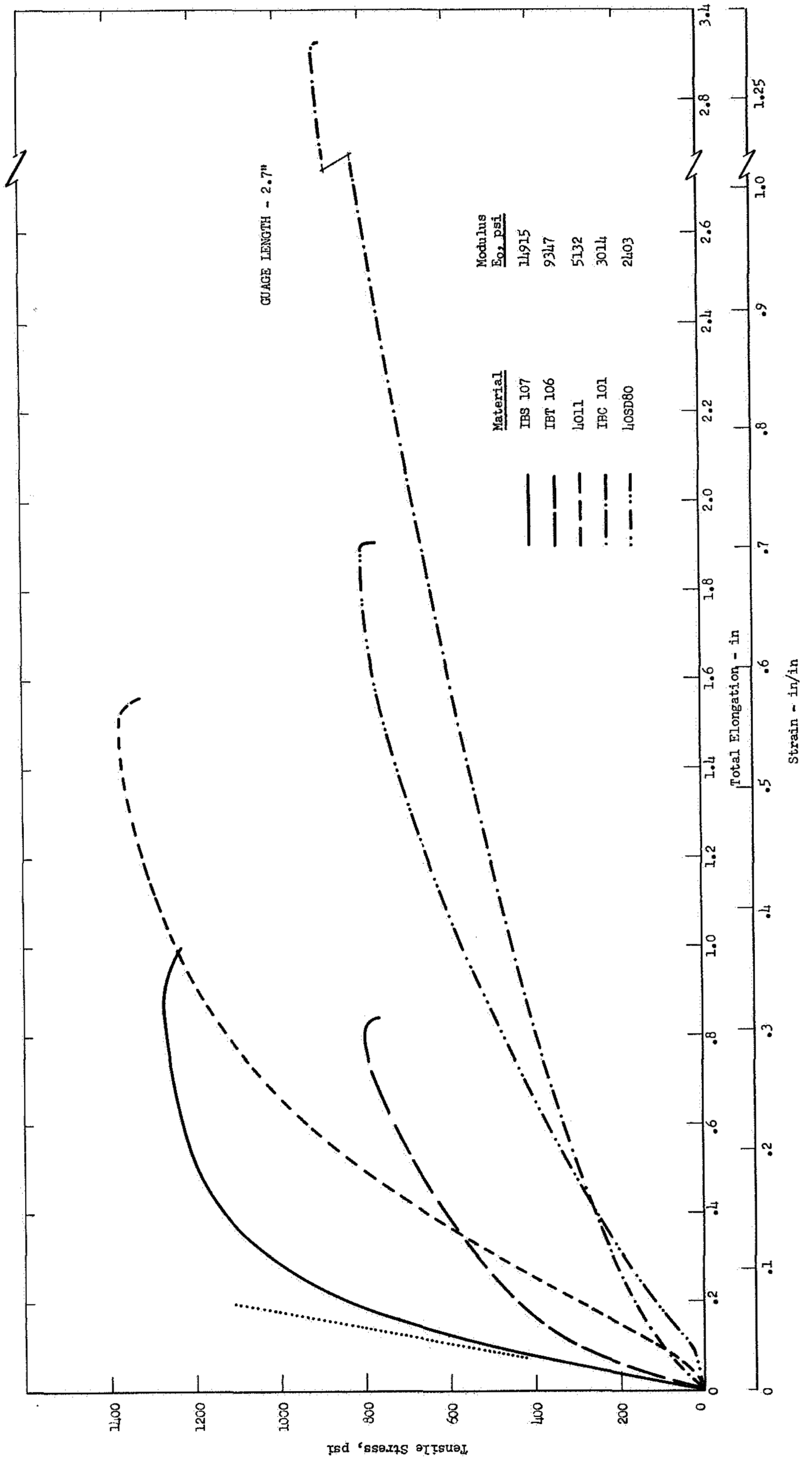
Figure 10, Sheet 3 of 4

NOTES: (For Sheets 2 and 3)

1. IBS-108 nomenclature synonymous with original IBS-105 identification.
2. S/I/L/P: 4130 steel/insulation/SD850-2 liner/ANB-3254 propellant.
3. Cured slabs of insulation bonded to steel plates.
4. P: failure in propellant.
   IP: adhesive failure at insulation-propellant-interface.
   IL: adhesive failure at insulation-liner-interface.
5. No liner required.
6. 50% IP, 50% P.
7. All bond samples failed randomly in the propellant unless otherwise noted.
8. Break within 1 mm of the propellant surface.
9. Break at the propellant-to-insulation interface, specimens being retested to verify data.
10. Use of SD850-2 liner on a residual specimen of IBC-111 which had been exposed to 180°F yielded a tensile value of 108 psi.

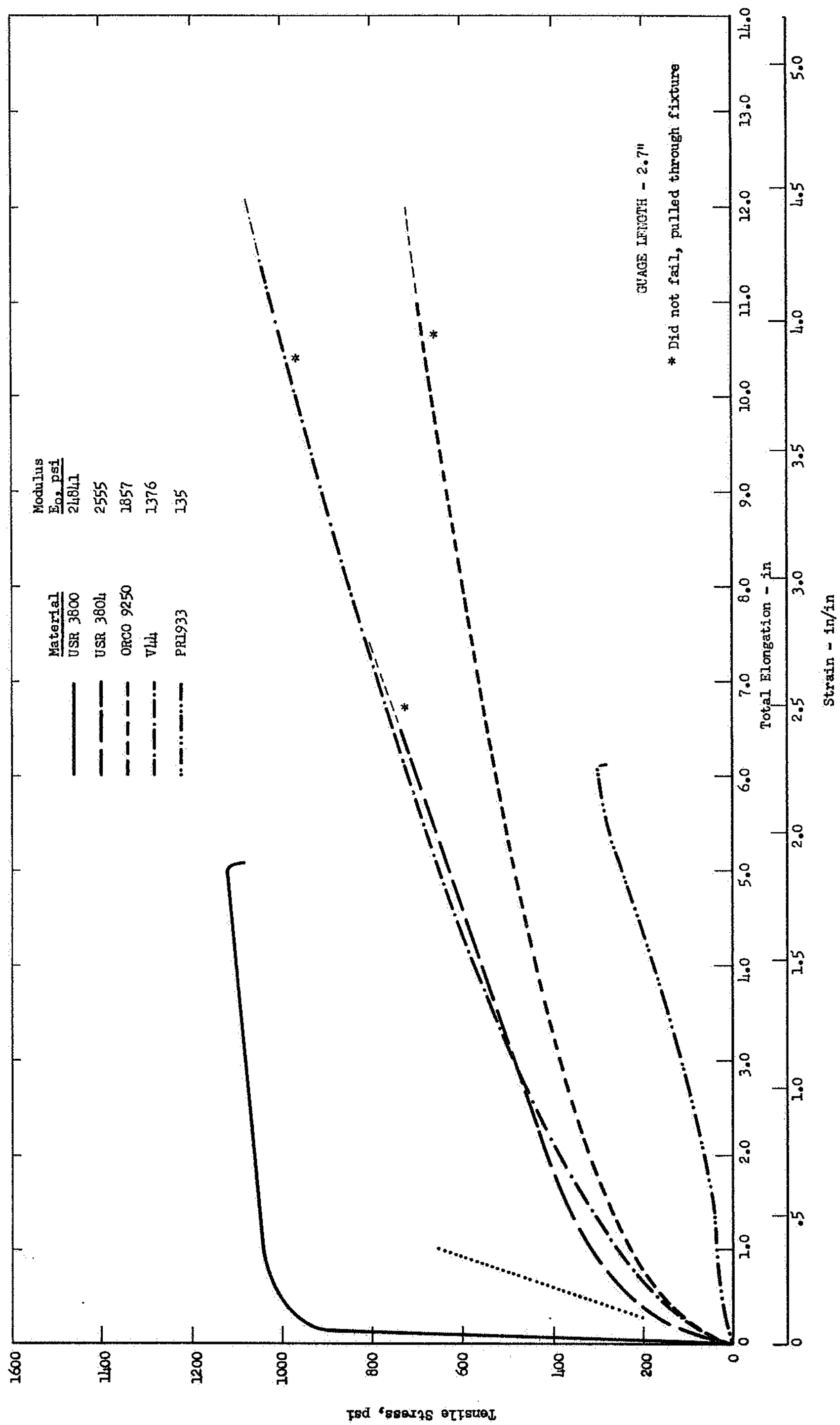
Property Measurement Data Summary

Figure 10, Sheet 4 of 4



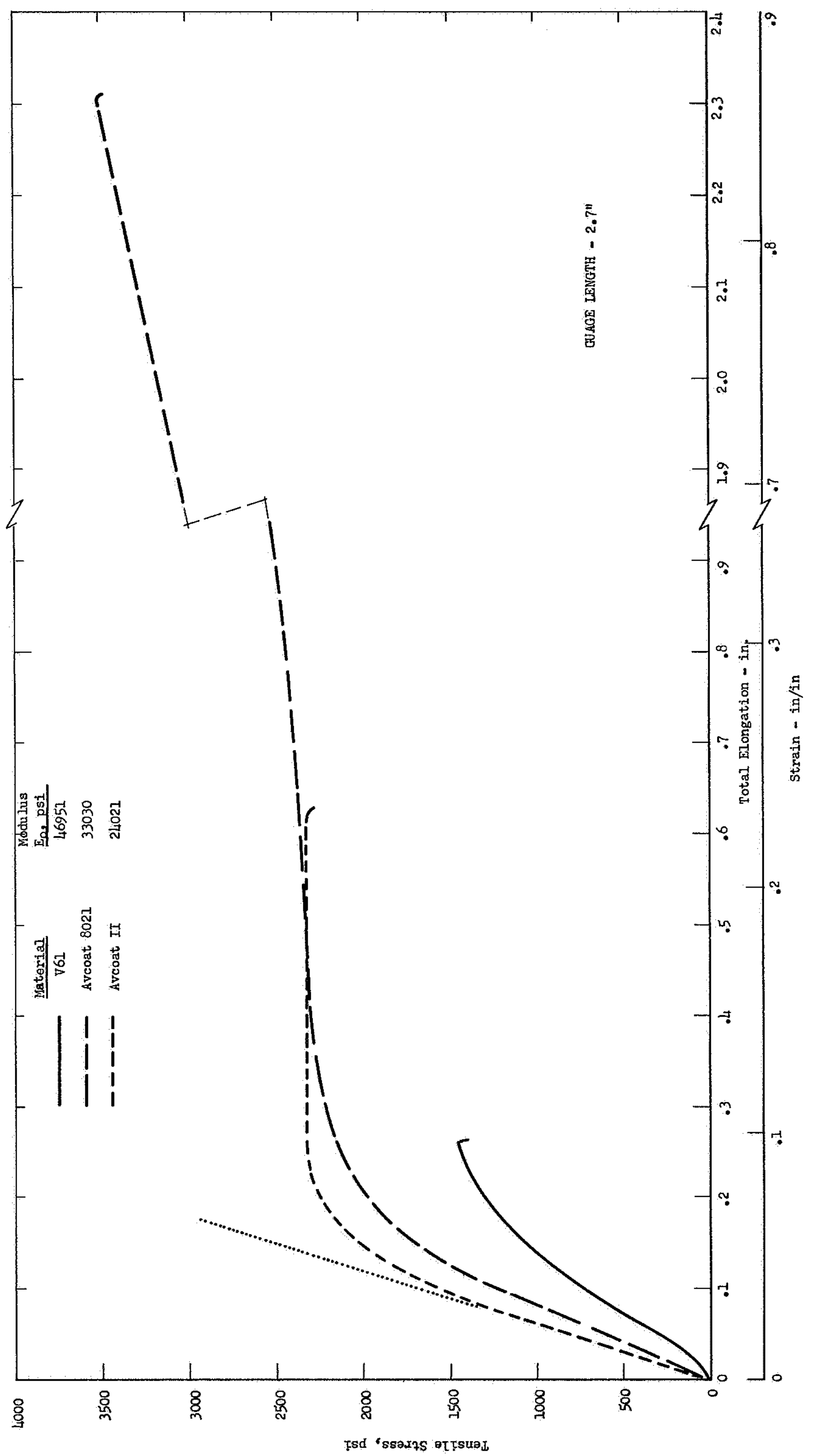
Typical Stress-Strain Diagrams for Insulation Materials

Figure 11, Sheet 1 of 4



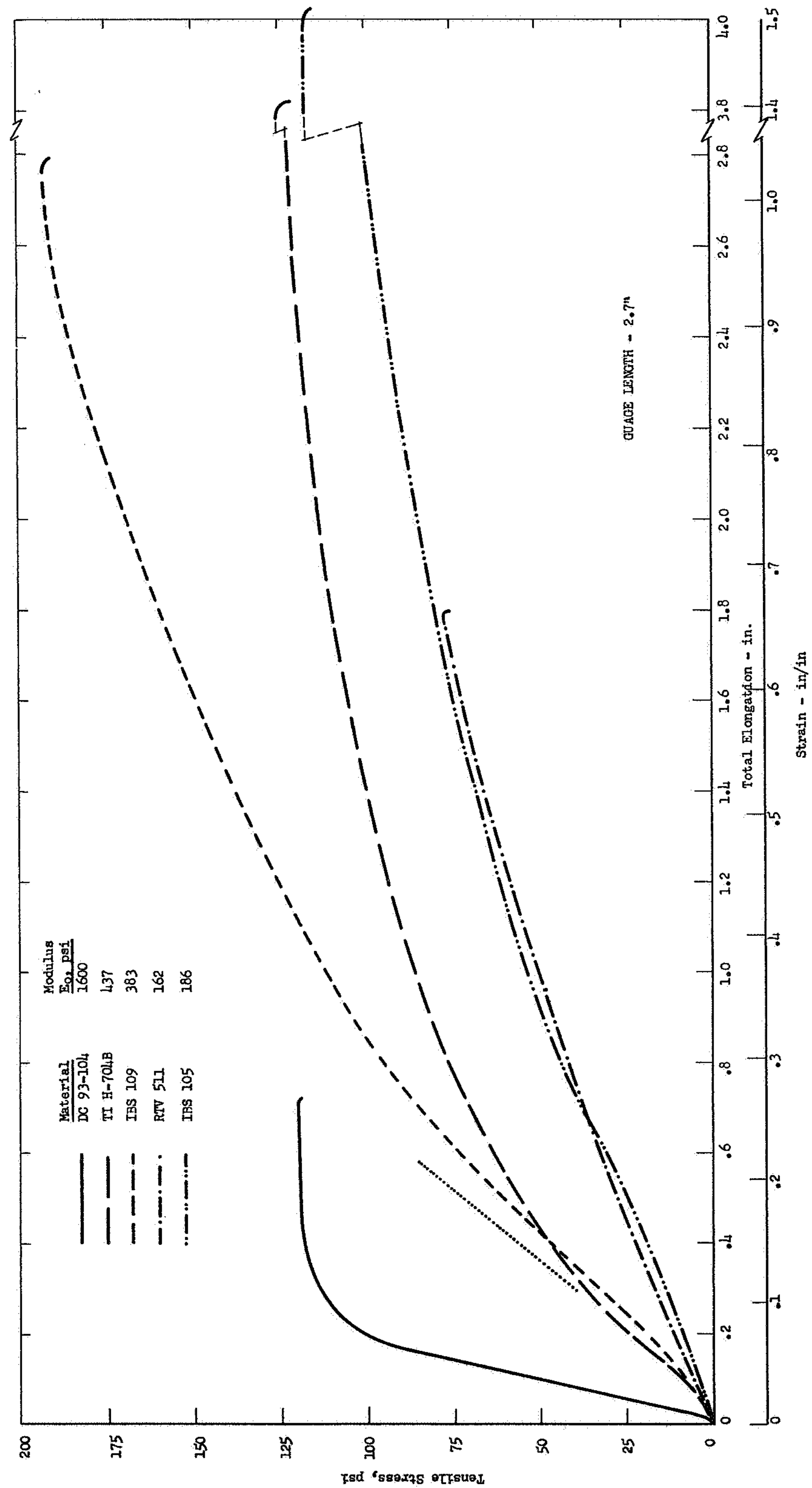
Typical Stress-Strain Diagrams for Insulation Materials

Figure 11, Sheet 2 of 4



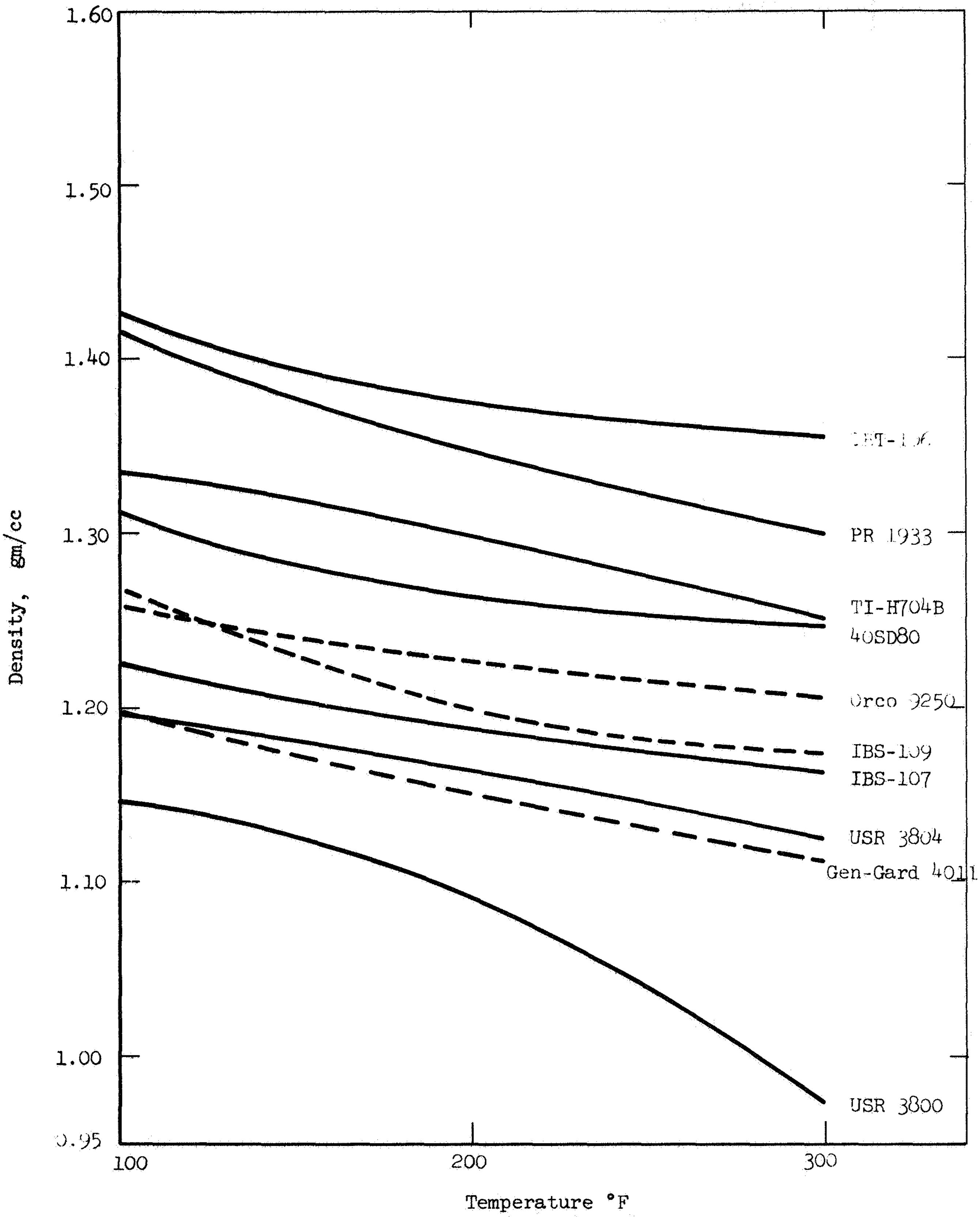
Typical Stress-Strain Diagrams for Insulation Materials

Figure 11, Sheet 3 of 4



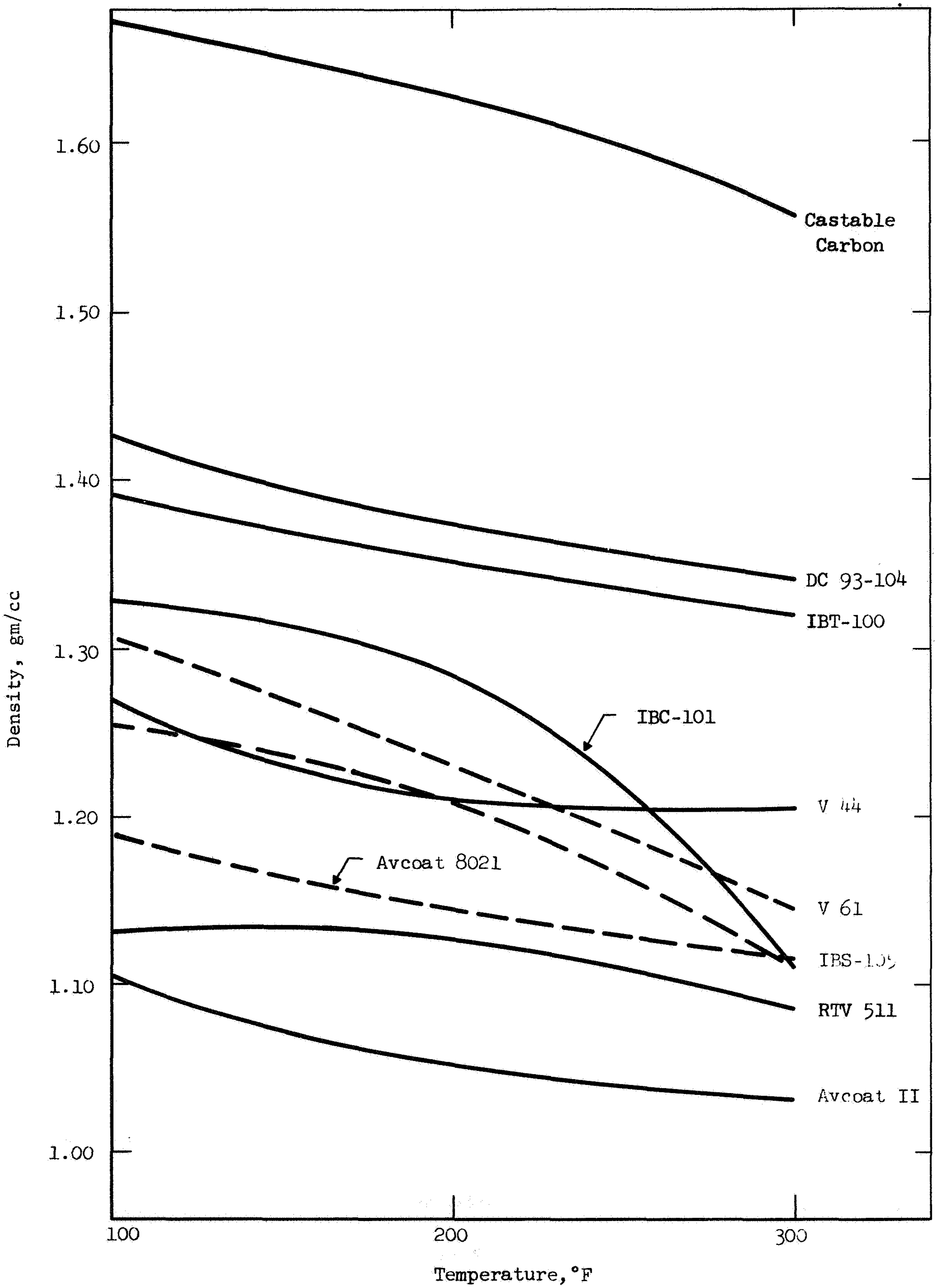
Typical Stress-Strain Diagrams for Insulation Materials

Figure 11, Sheet 4 of 4



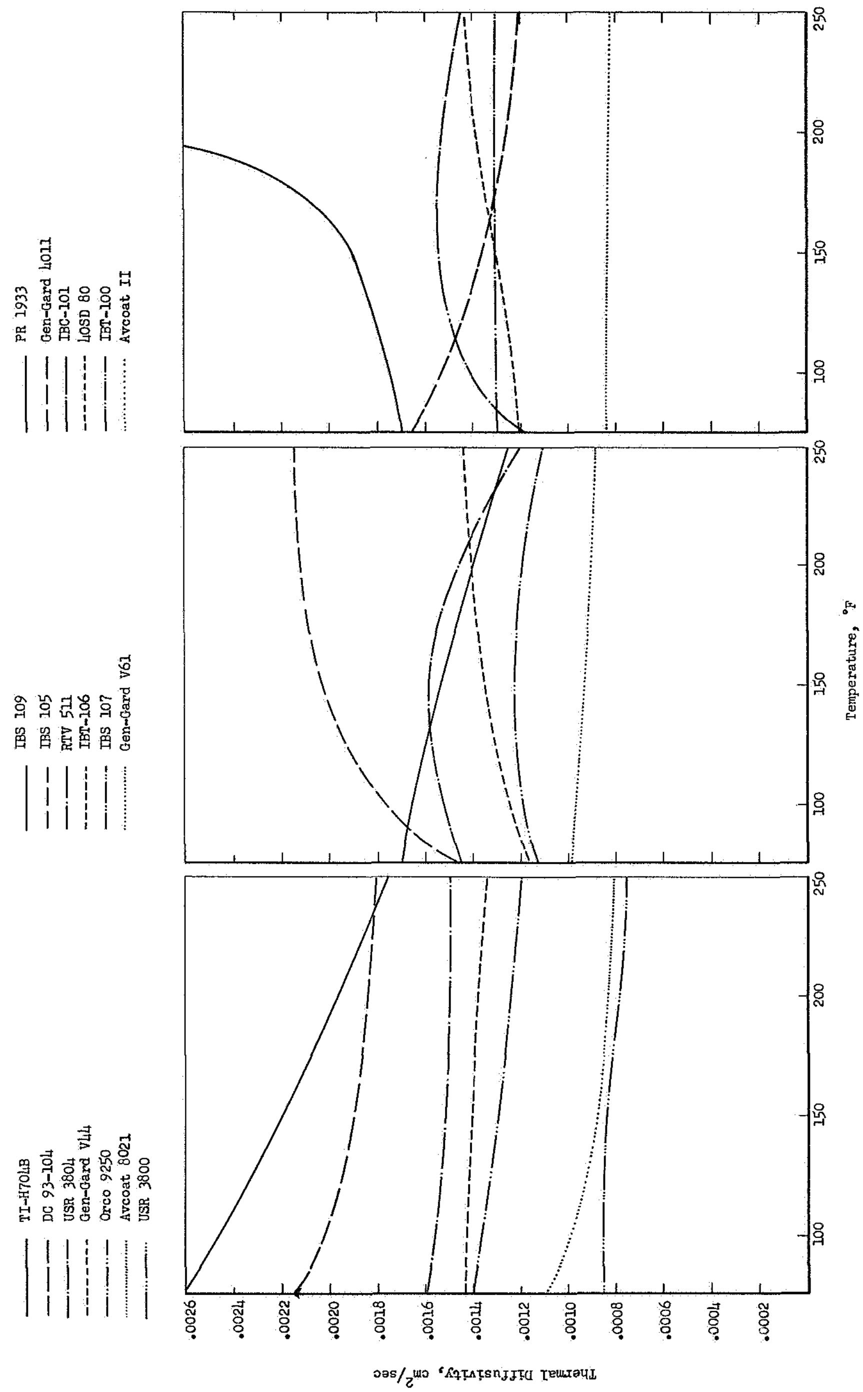
Density of Insulation Materials

Figure 12, Sheet 1 of 2



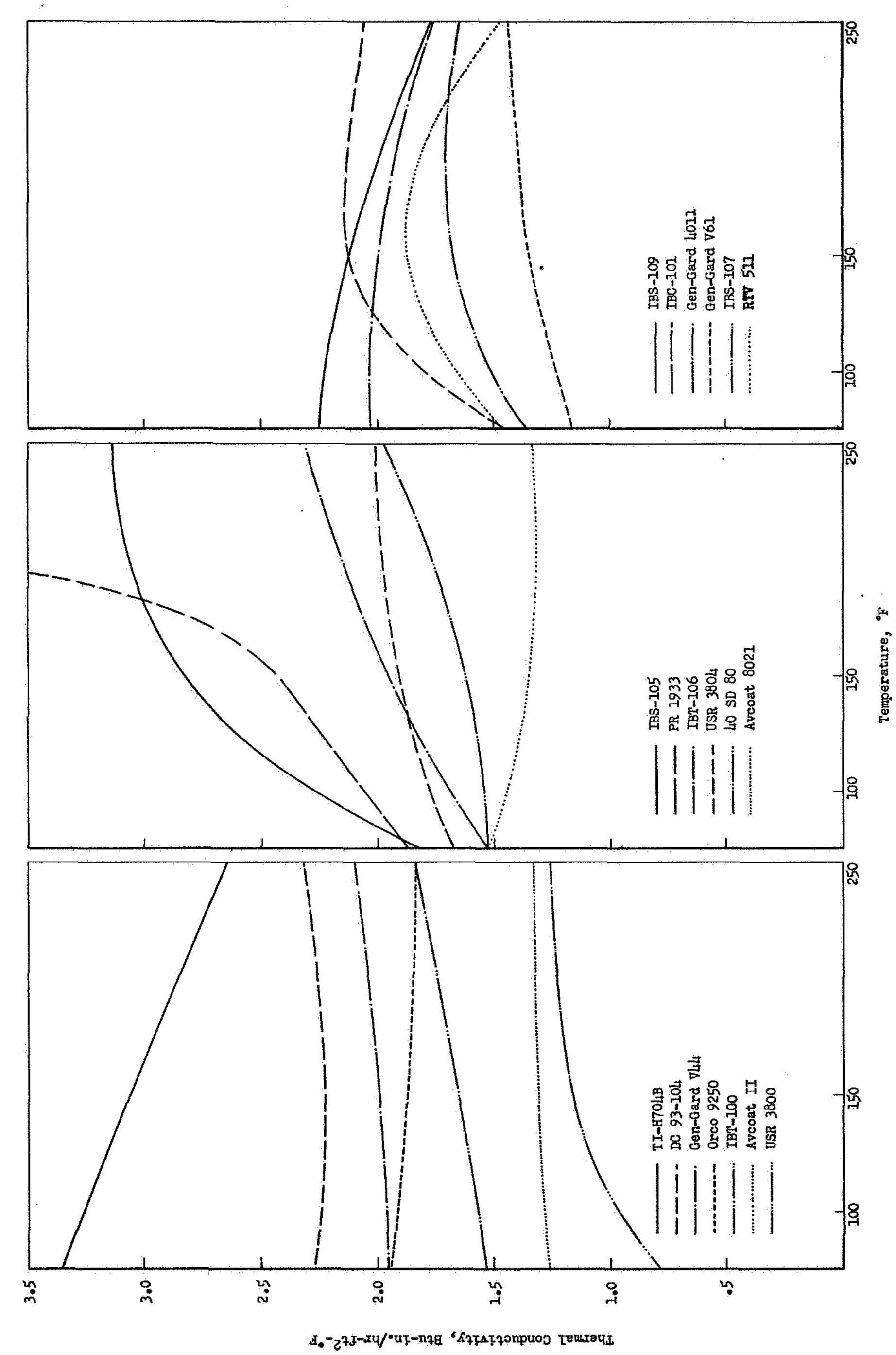
Density of Insulation Materials

Figure 12, Sheet 2 of 2



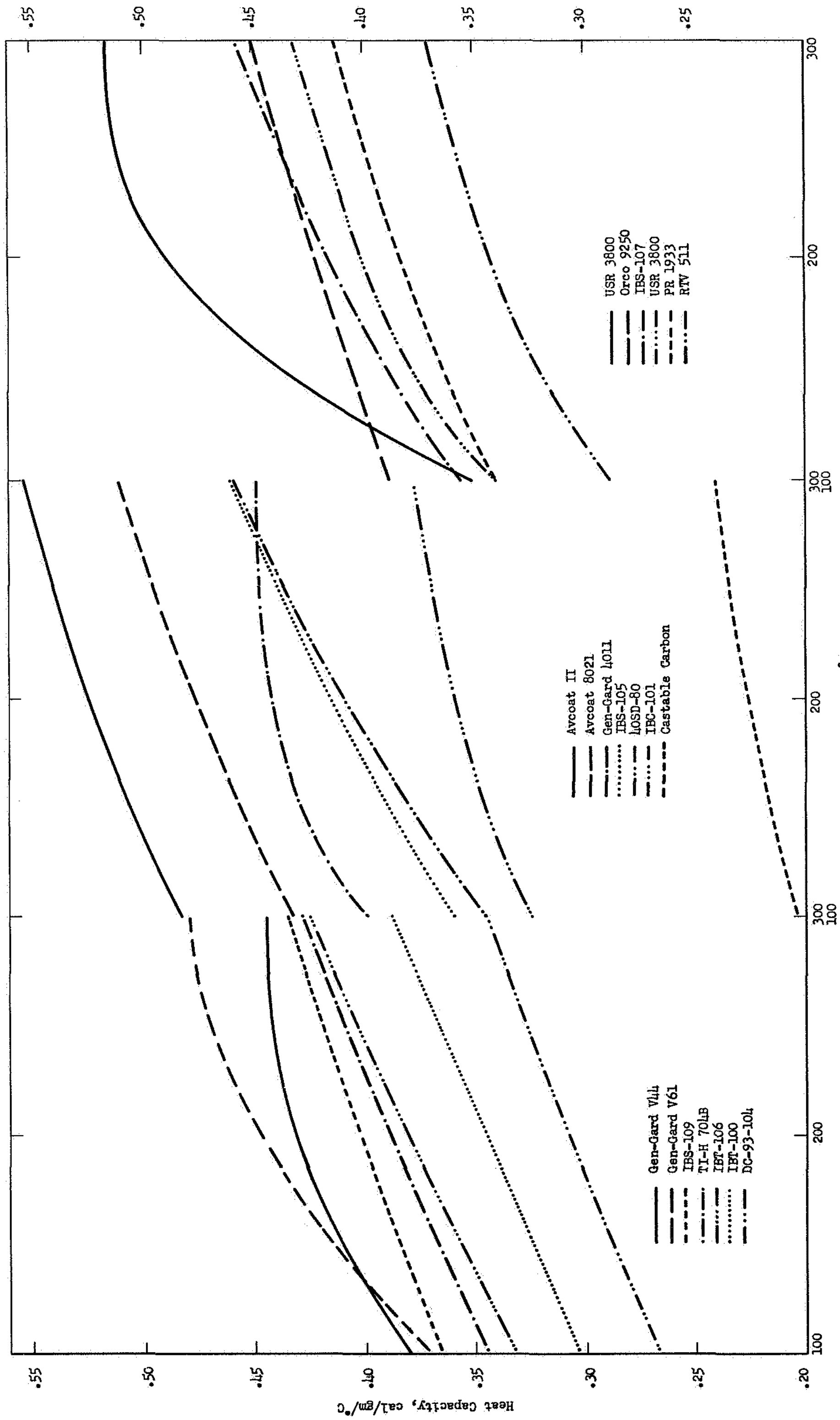
Thermal Diffusivity-vs-Temperature

Figure 13



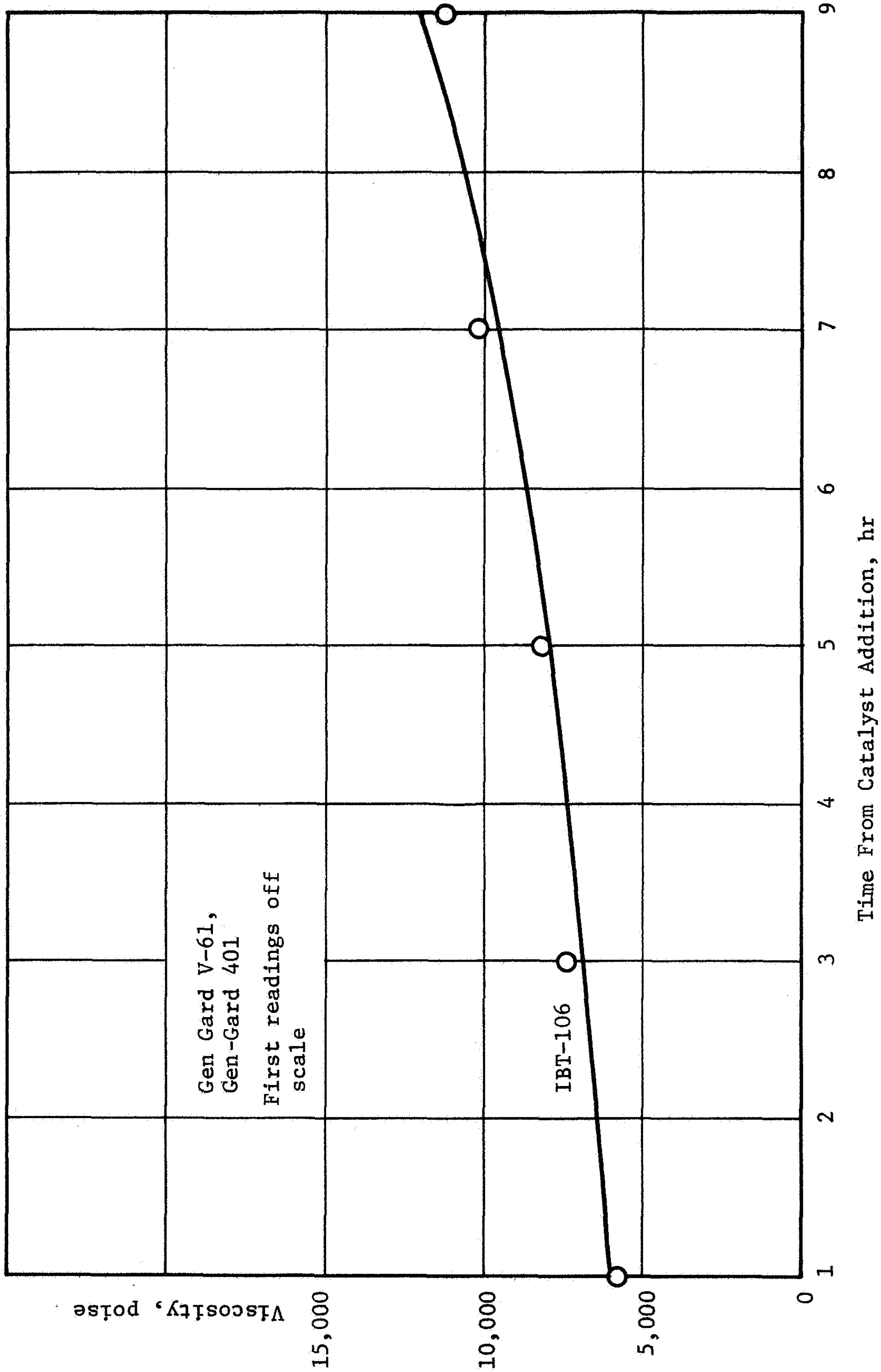
Thermal Conductivity-vs-Temperature

Figure 14



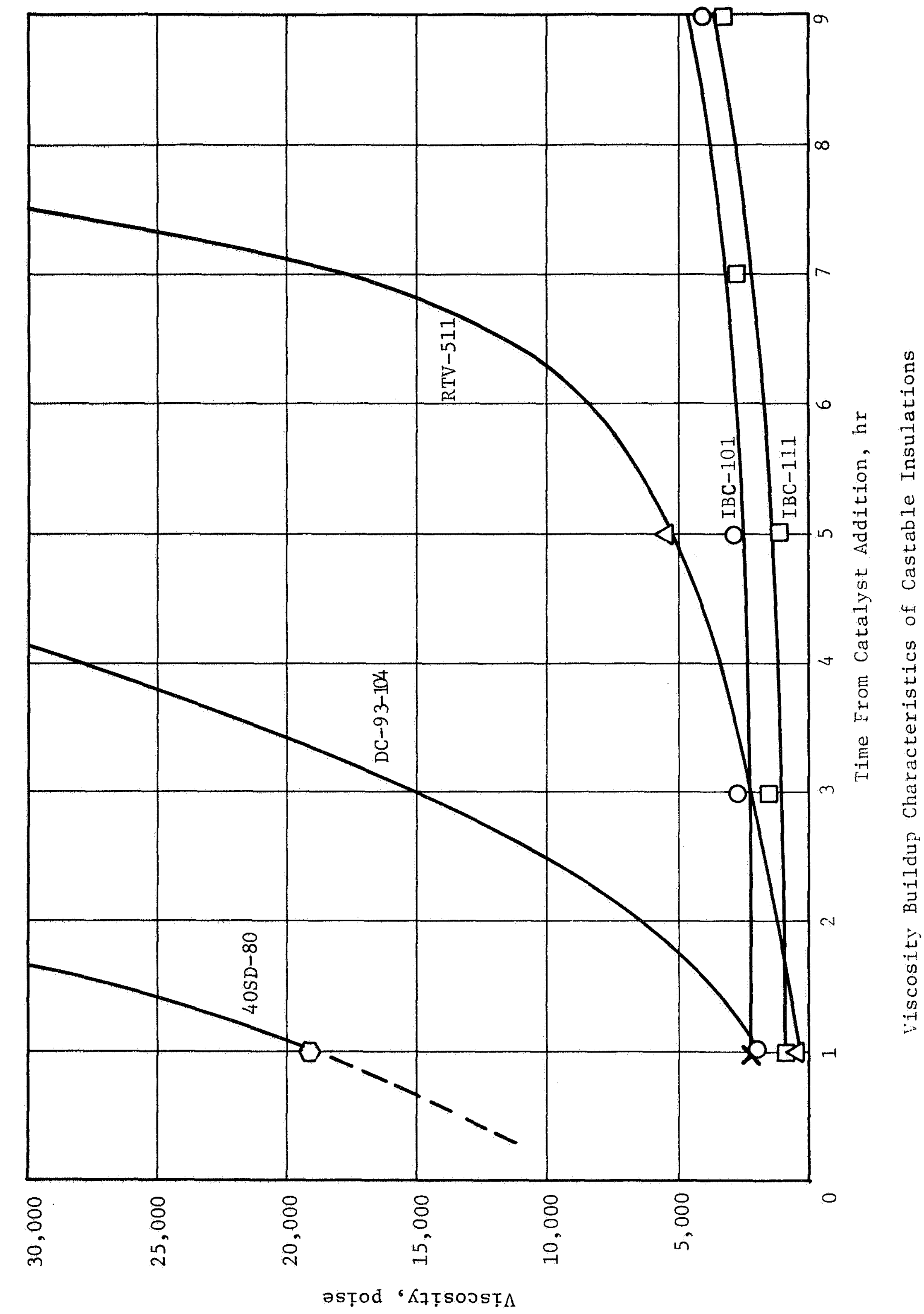
Heat Capacity-vs-Temperature

Figure 15



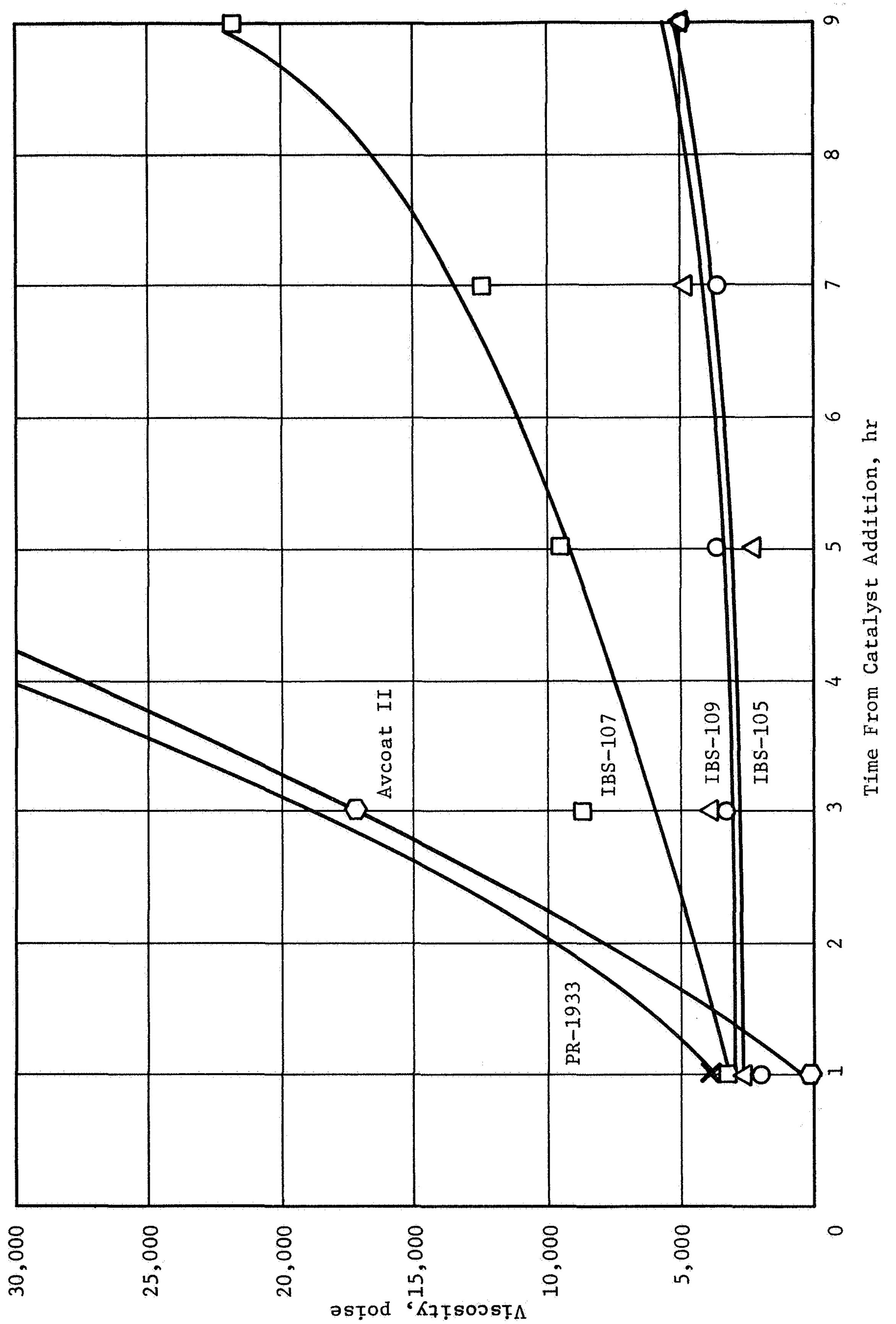
Viscosity Buildup Characteristics of Trowelable Insulations

Figure 16



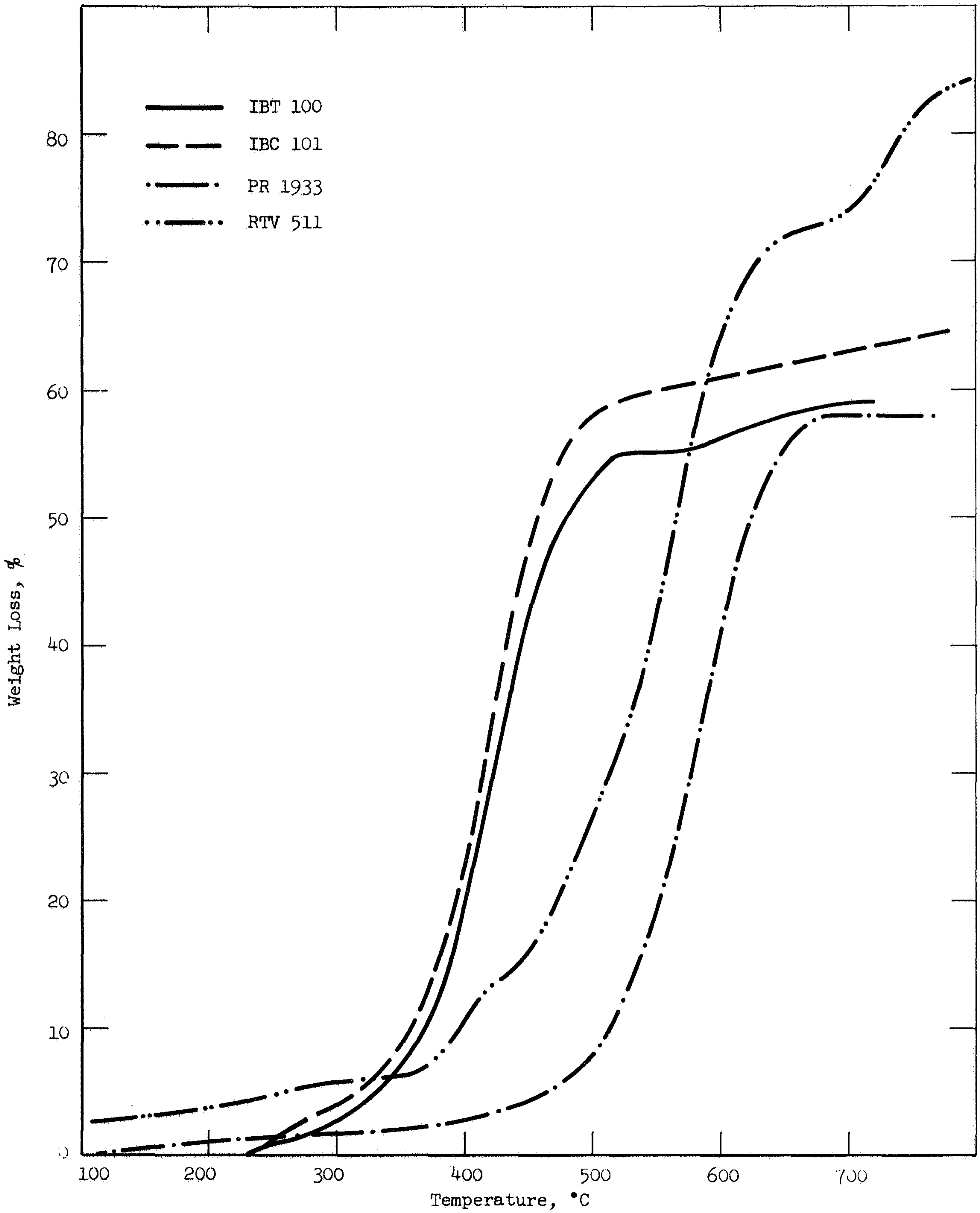
Viscosity Buildup Characteristics of Castable Insulations

Figure 17



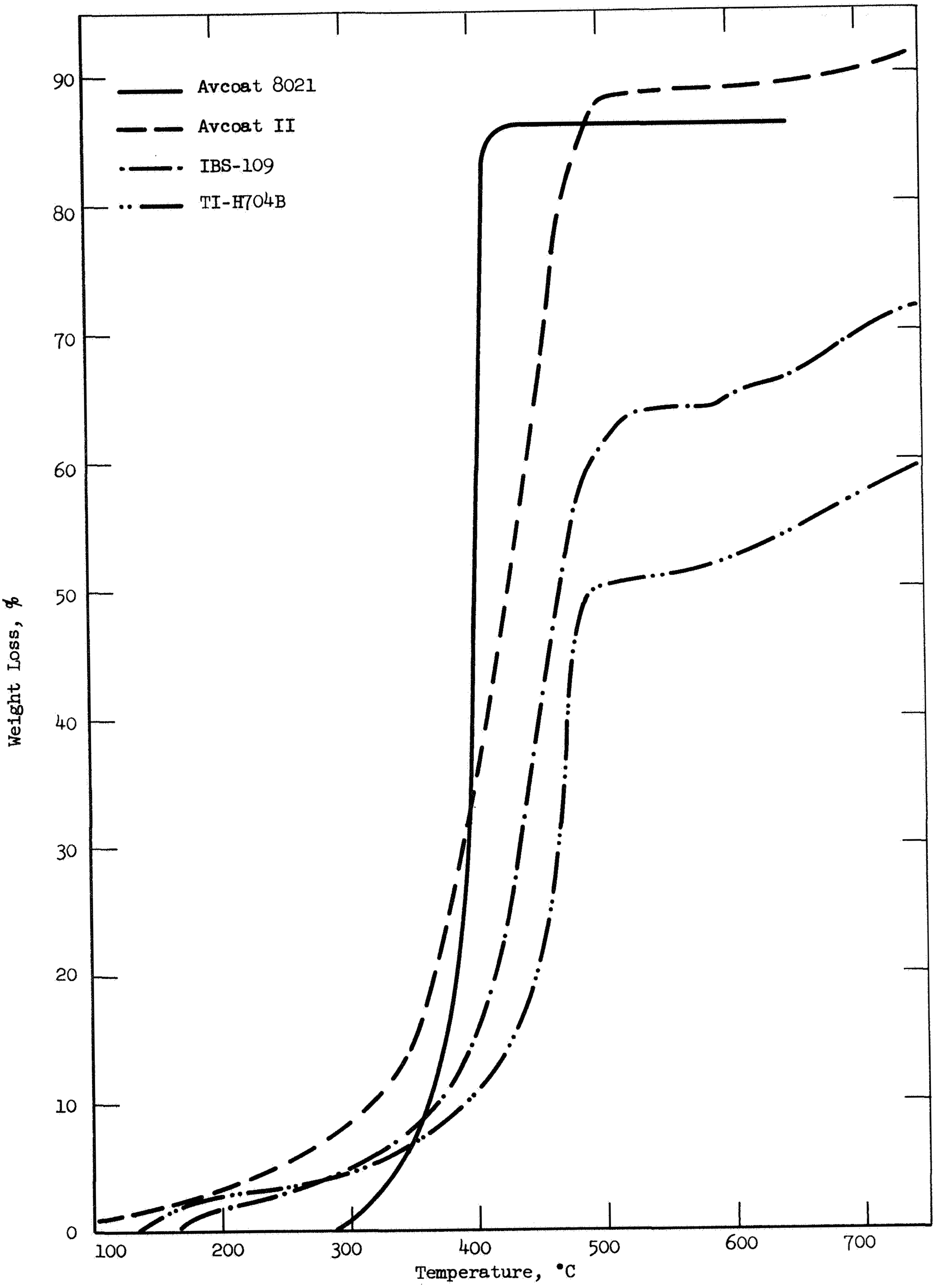
Viscosity Buildup Characteristics of Sprayable Insulations

Figure 18

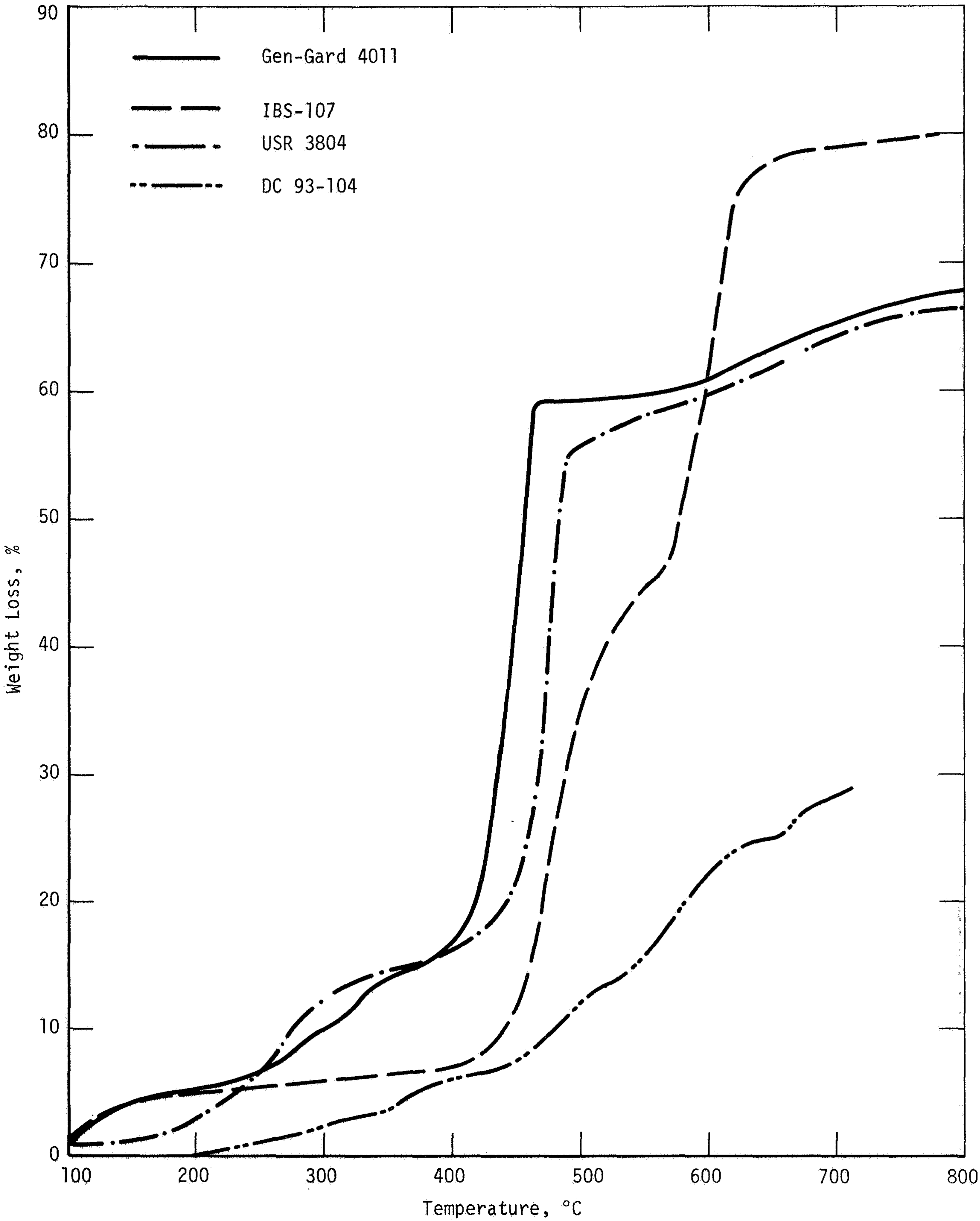


Thermogravimetric Analysis of Insulation Materials

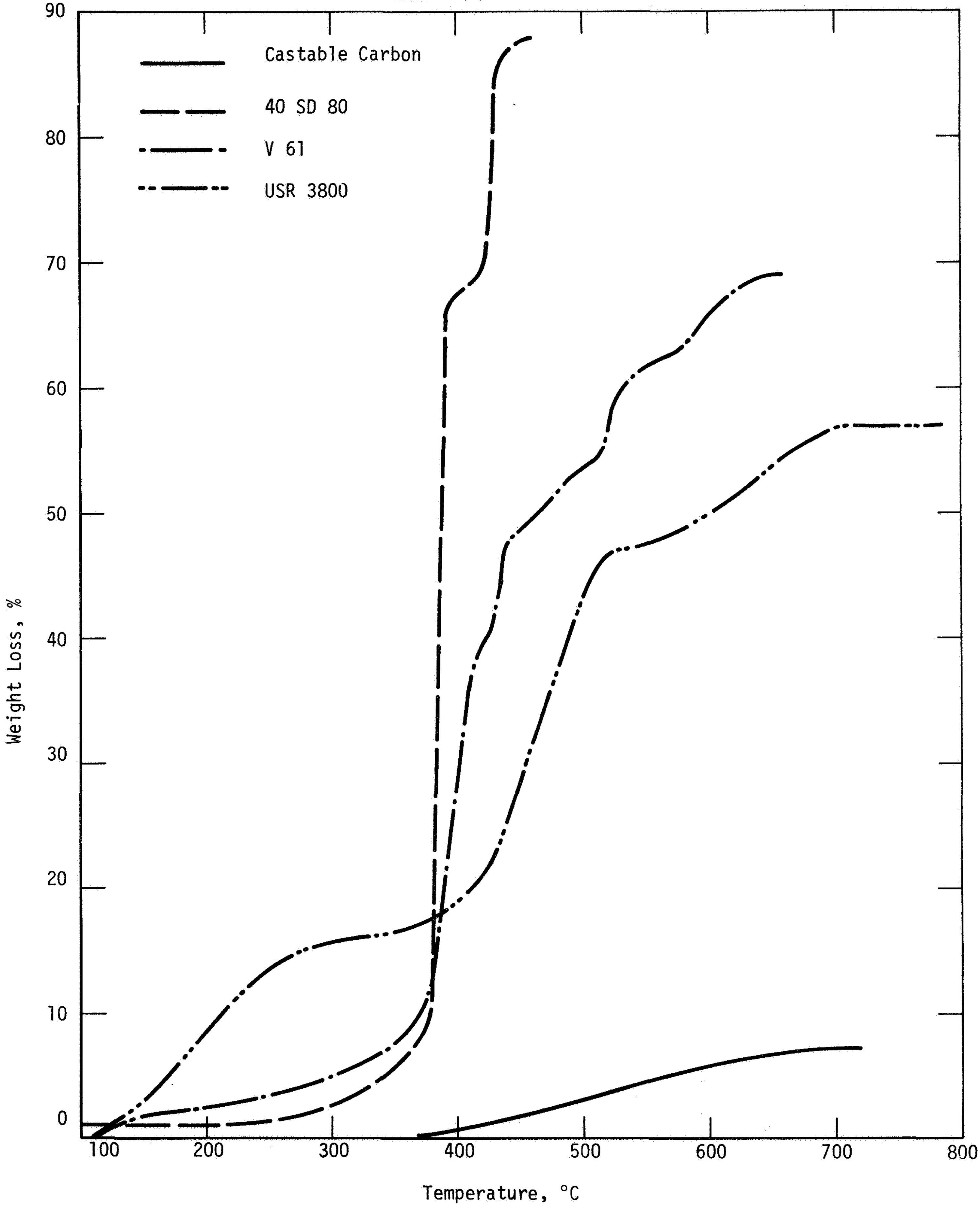
Figure 19, Sheet 1 of 5



Thermogravimetric Analysis of Insulation Materials
Figure 19, Sheet 2 of 5

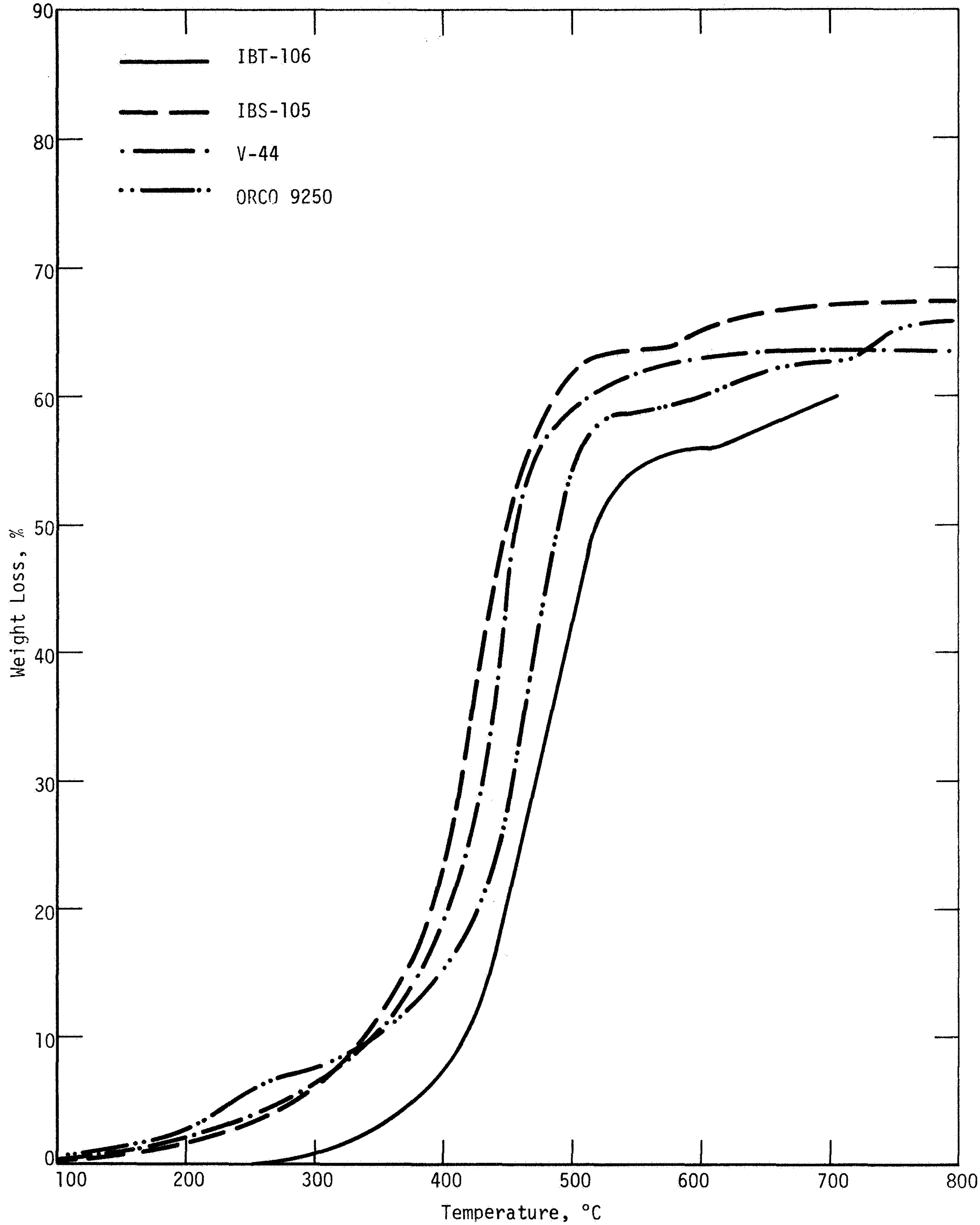


Thermogravimetric Analysis of Insulation Materials
Figure 19, Sheet 3 of 5



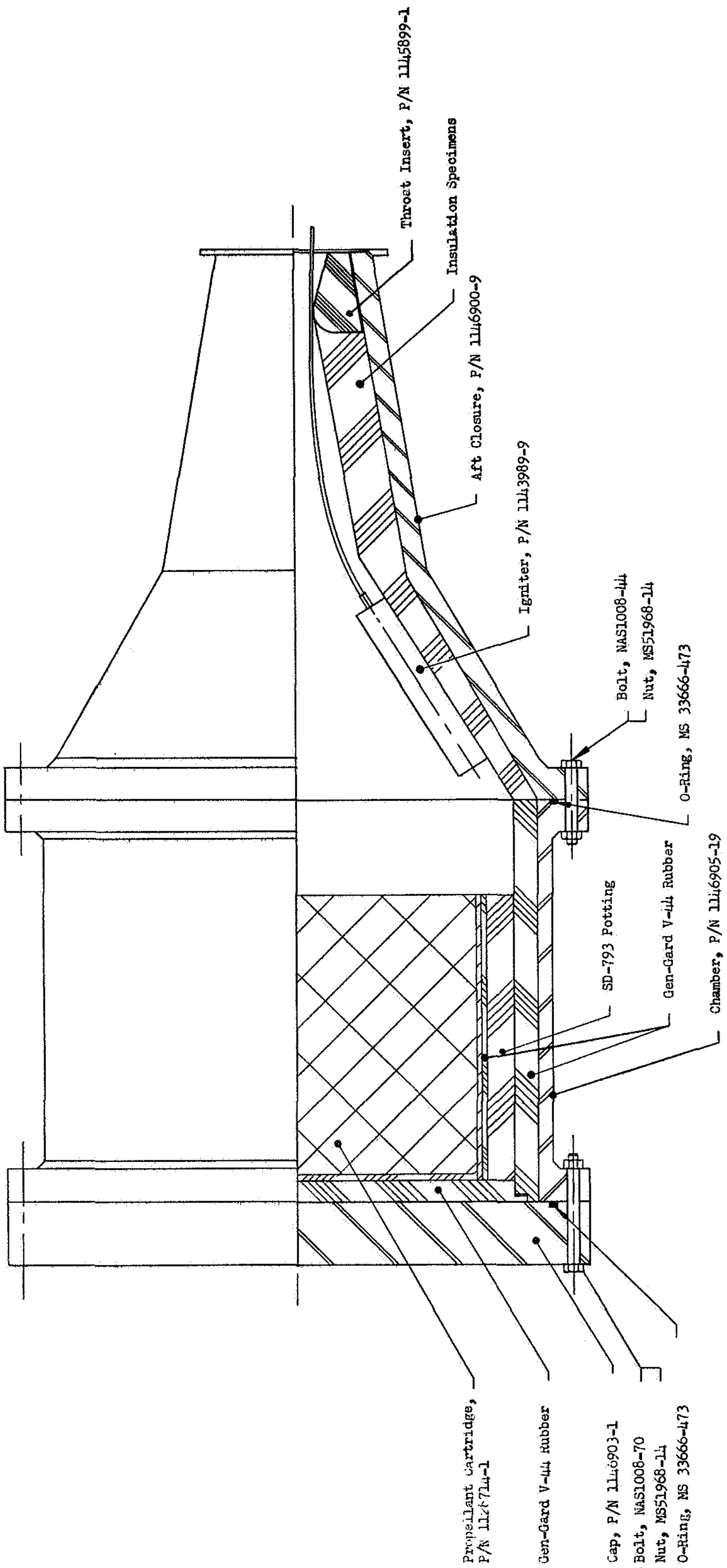
Thermogravimetric Analysis of Insulation Materials

Figure 19, Sheet 4 of 5



Thermogravimetric Analysis of Insulation Materials

Figure 19, Sheet 5 of 5



LMISD Test Motor Configuration

Figure 20

M E M O R A N D U M

TO:	D. L. Nachbar	10 June 1968 JMK:wjs
FROM:	J. M. Kovacs	2019A:3252:807
SUBJECT:	Preliminary Stress Analysis of LMISD Test Motor	
DISTRIBUTION:	E. P. Eales, R. D. Entz, R. Knapp, File	
ENCLOSURE:	(1) Detailed Stress Calculations	

A preliminary structural evaluation of the LMISD test motor primary components has been completed for a design pressure of 720 psi, approximately 115% of MEOP, with results shown in the table below. The small margins of safety should not be of concern, since they are based upon conservative analytical methods used to simplify the stress calculations.

TABLE OF MINIMUM MARGINS OF SAFETY
(Design Pressure of 720 psi)

Component	Stress	Allowable	Mode	Margin of Safety
Cover Plate	16,600	36,000	Bending	1.15
Bolt	18,000(lb)	20,800(lb)	Tension	0.165
Chamber	8,136	36,000	Tension	3.20
Nozzle Housing	30,170	36,000	Bending	0.20
Asbestos Phenolic	282	5,400	Shear	Large

$$MS = \frac{\text{Calculated Stress}}{\text{Allowable}} - 1$$

Per your request, no thermal stress analysis of the graphite insert was performed. A simplified heat transfer analysis performed by the Aerophysics Department showed the asbestos phenolic/graphite interface to reach about 800°F, with the steel shell remaining at ambient for the 20 second duration.

A nominal bolt torque will be adequate to prevent leakage of the large diameter chamber joints, maximum separation conservatively estimated at less than 0.012 inches at the O-Ring seal.

J. M. Kovacs
Engineering Specialist
SRO Stress Group
Propulsion Division

Approved by:

R. D. Entz, Manager
SRO Stress Group
Propulsion Division

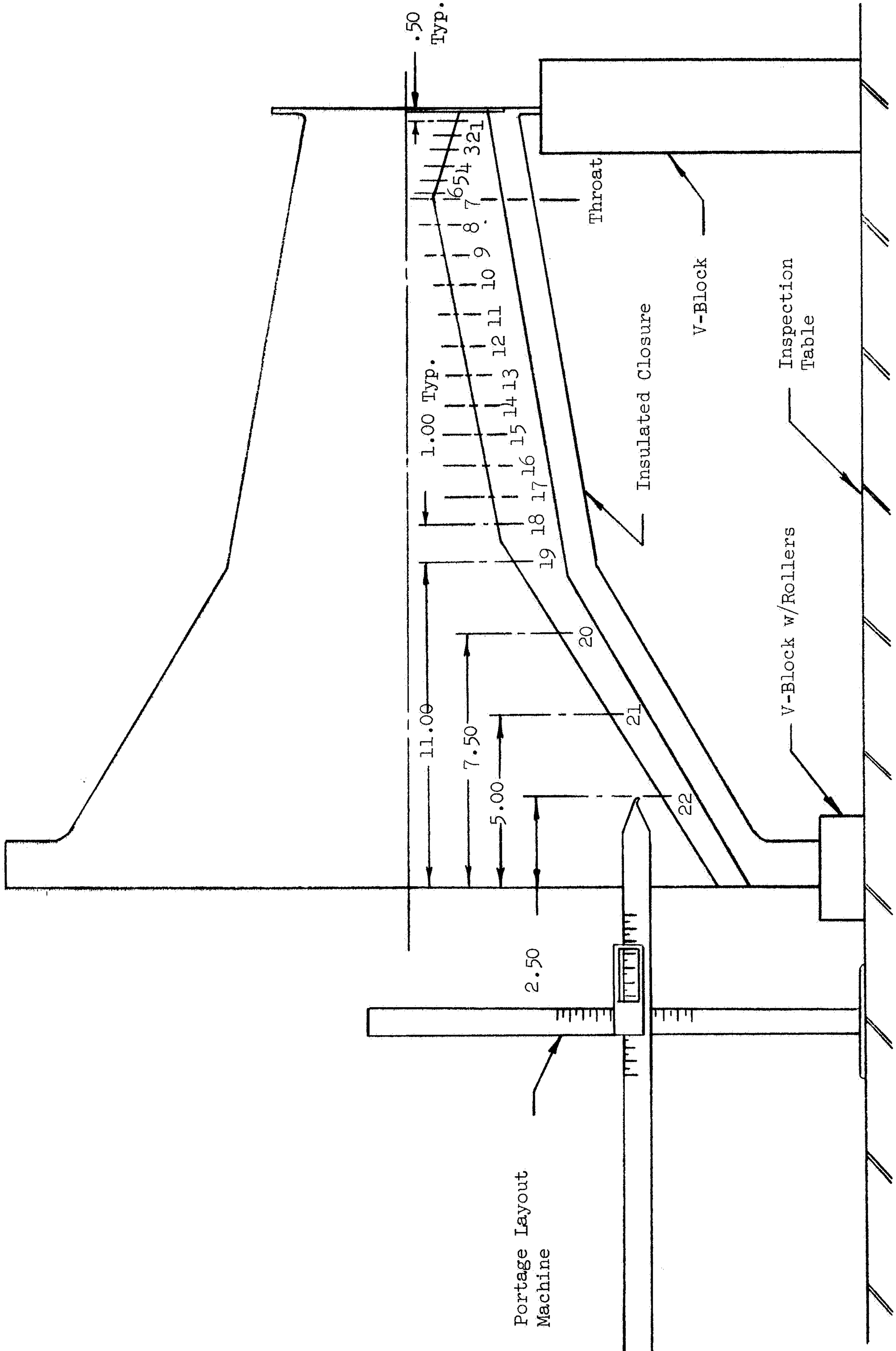
Stress Analysis of LMISD Test Motor

Figure 21

1. X-Ray	Accuracy good. Requires precise placement of film and great care in interpretation. Film provides picture of material cross-section.
2. Template	Accuracy fair to good. Requires feeler gage and micrometer in conjuction with template. Method is simple.
3. Cast	Accuracy good. Requires care in placement of casting dams. Good deal of handling. Method involved.
4. CORDAX 300	Accuracy excellent. Method relative simple. No interpretation or reading required of operator. Data is printed-out by machine.
5. Portage Layout Machine	Accuracy good. Method simple, but requires repeatable set-up and reading by operator.

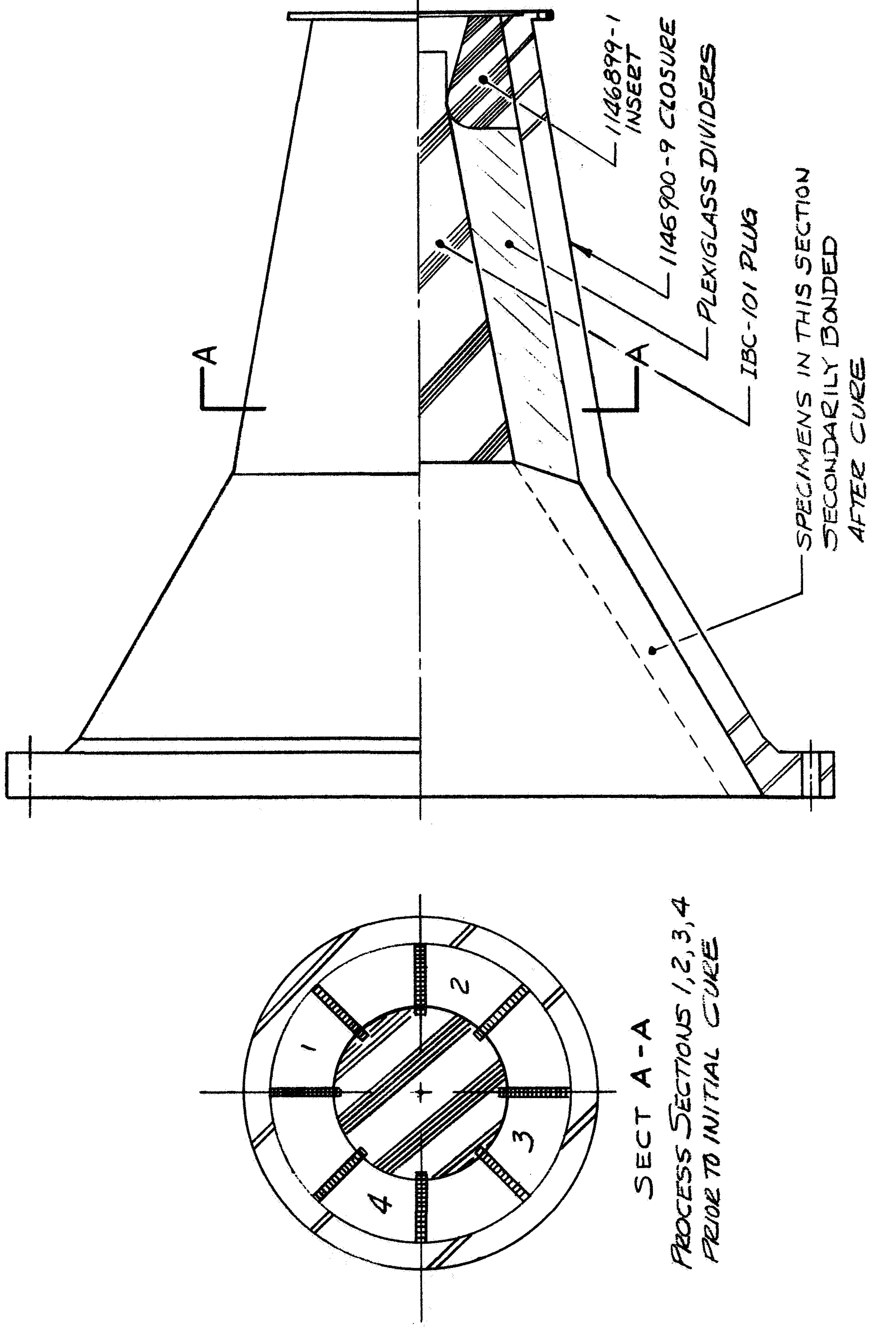
Contour Measurement Method Comparison

Figure 22



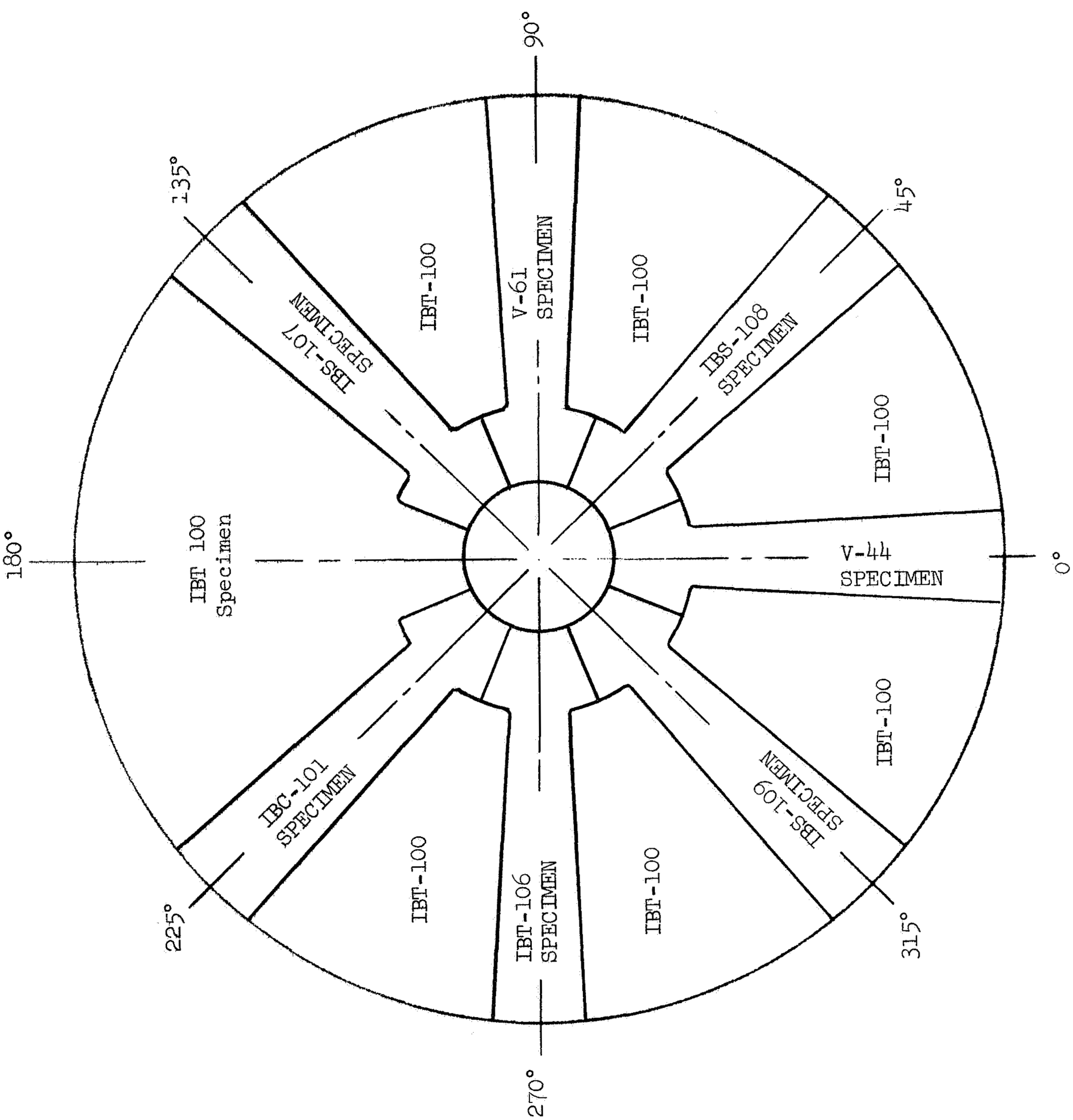
Setup for Layout of Test Motor Closure Insulation Specimen

Figure 23



Aft Closure Insulation Specimen Processing Setup

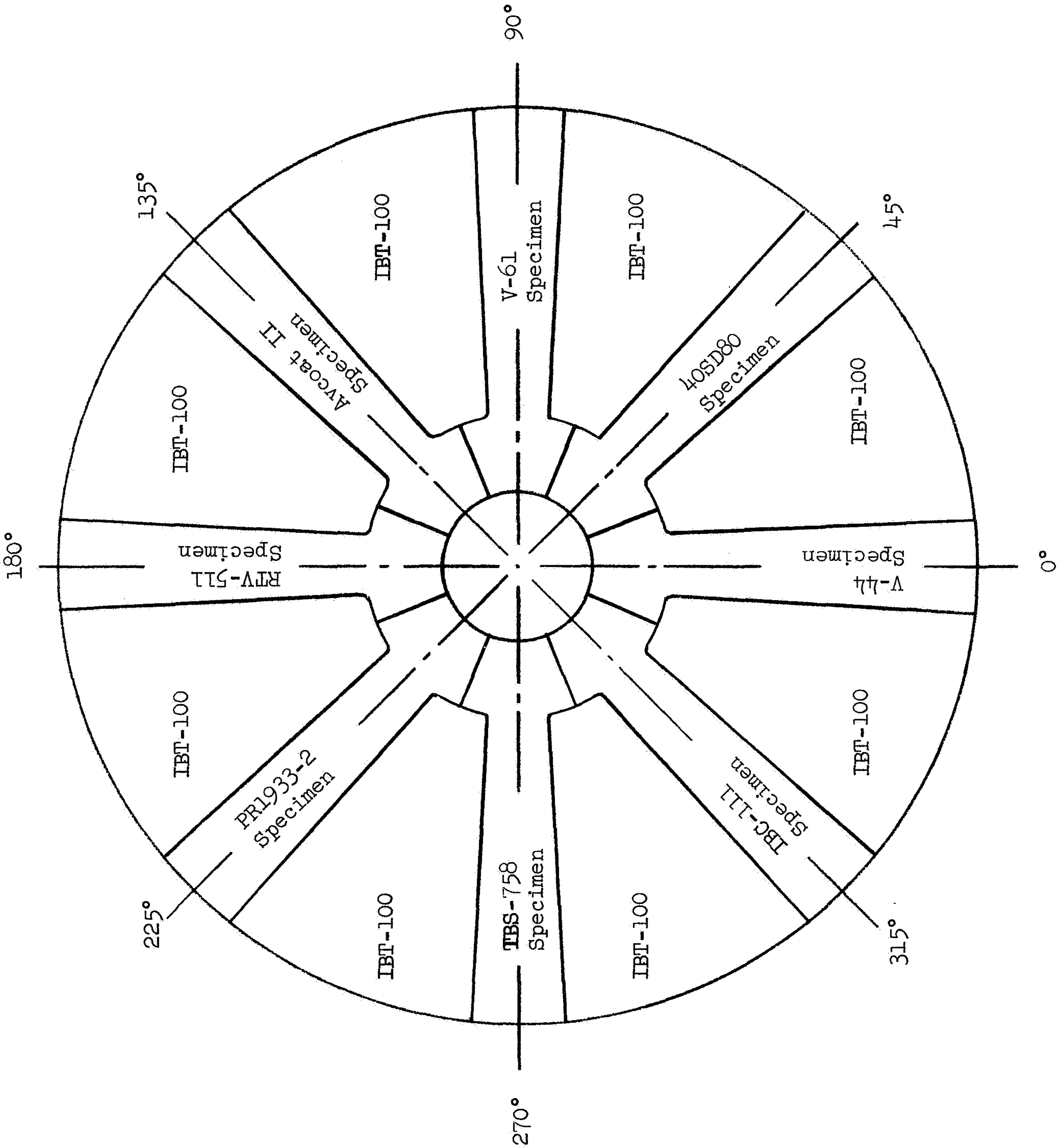
Figure 24



Scribed Mark on Nozzle
Standing Fwd Looking Aft

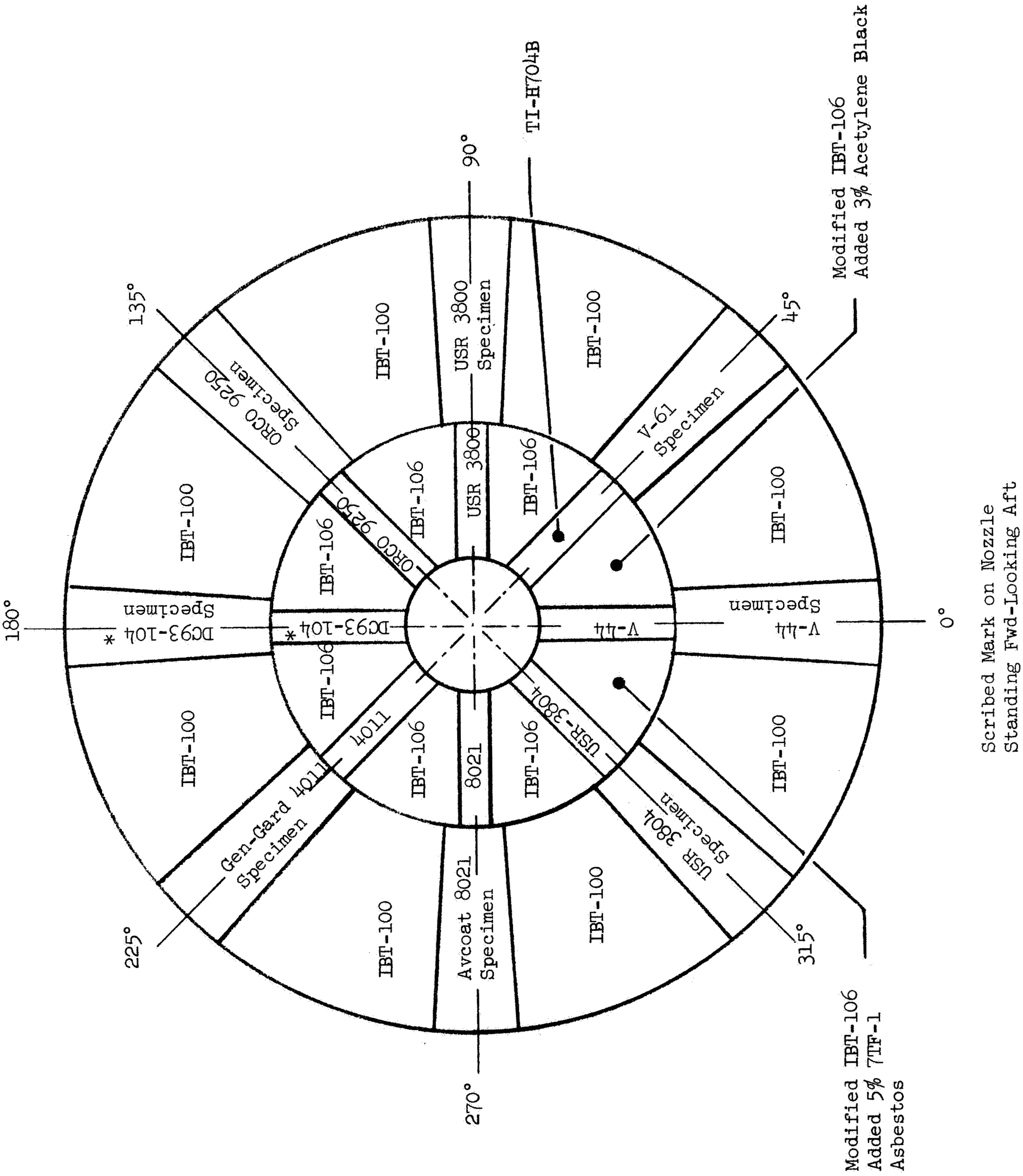
Specimen Location in Nozzle SN I-1

Figure 25



Scribed Mark on Nozzle
Standing Forward Looking Aft
Specimen Location in Nozzle S/N I-2

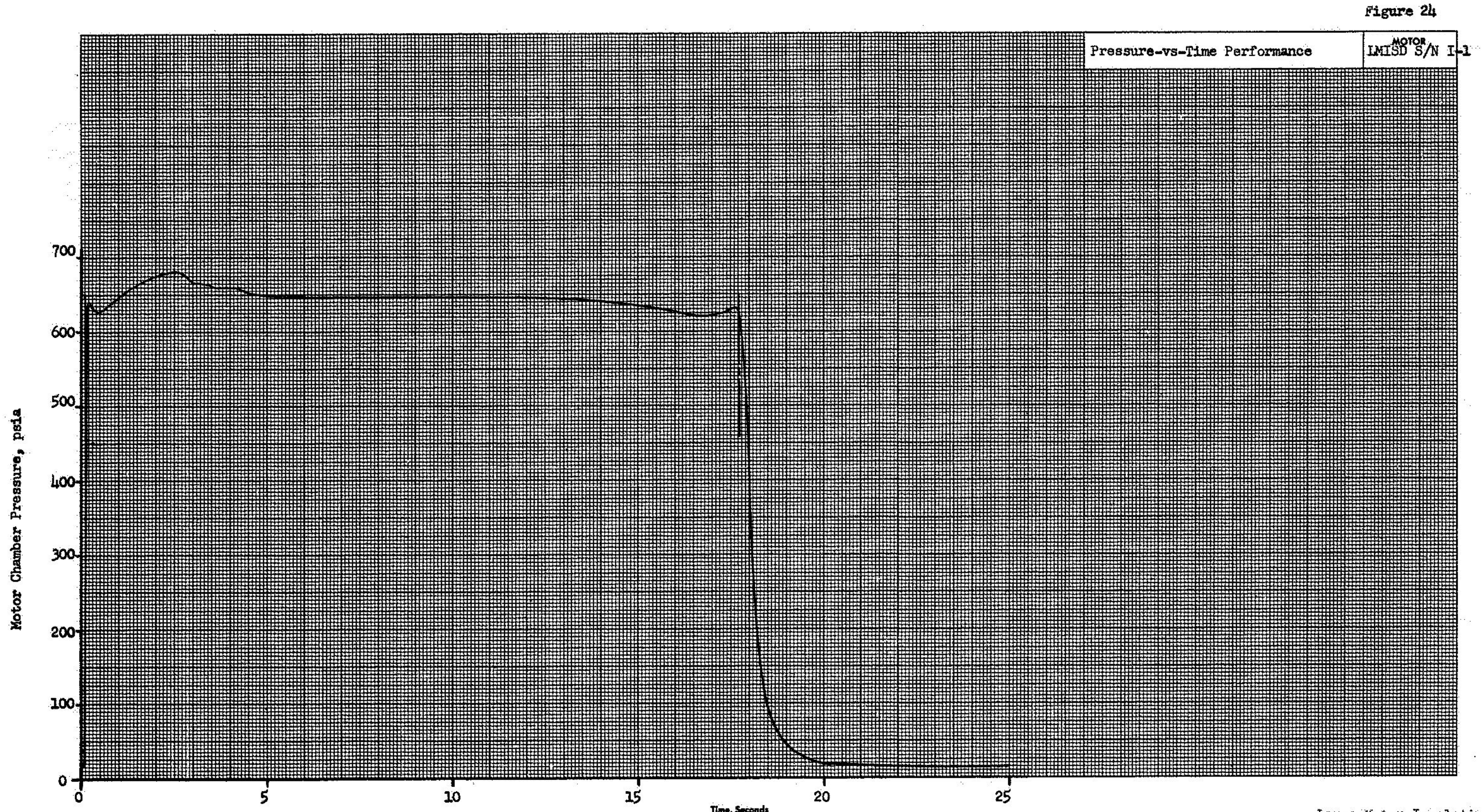
Figure 26



Specimen Location in Nozzle S/N I-3A

*Original Identification was
S/N I-3; Damaged DC93-104
Removed and Replaced with IBT-100

Figure 27



I, meas. -- lb-sec	Web duration 17.6 sec	Dt (initial) in 1/.813	2	3	4	Propellant ANB-3254	Port area (aft) -- in²
I, corr -- lb-sec	Web av. press 640 psia	Dt (final) in				Weight 207 lb	Af/At (aft) -- K --
Is -- lb-sec/lb	Burning rate 0.781 in/sec	De in				Density -- lb/in³	Liner --
Is-std -- lb-sec/lb	∫Pdt 11,275 psia-sec	Ae/At (initial)				Batch No. B-473	Total motor wt -- lb
I, vac -- lb-sec	∫P At dt -- lb-sec	At (initial) 2.58 in² At (final) in²				Configuration End Burning	Length -- in Dia -- in
Is-vac -- lb-sec/lb	∫P dt -- psia-sec	Div half angle 15°				Grain length 13.75 in	Cond temp 70 ± 5 °F
Is-std -- lb-sec/lb	At av -- in²	Throat matl ATJ Graphite				Grain O.D. 17.01 in	Ign prim. charge 300 g
Cw -- lb/lb-sec	Cf interval --	Kf --	Ign interval -- ms			Web thickness -- in	Main charge 5 g

Remarks:

Program	Large Motor Insulation Development
Contract	NAS3-11224
Test No.	1231-D01-OK-001
Assy Dwg No.	1146901-9
Date fired	10/18/68
Prep. By	D.L. Nachbar

AEROJET-GENERAL CORPORATION
SACRAMENTO · CALIFORNIA

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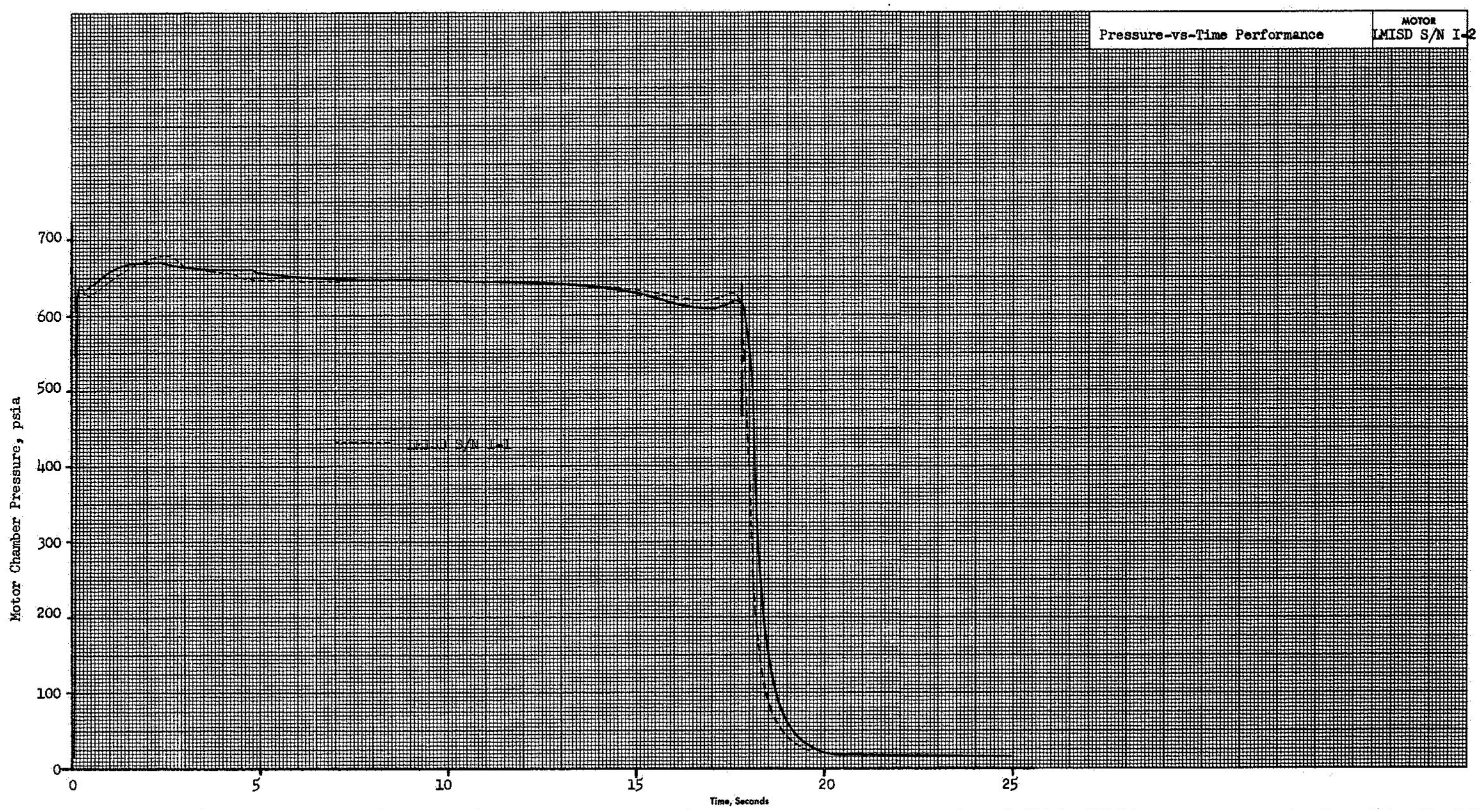
Pressure-vs-Time Performance, Motor S/N I-1

Figure 28



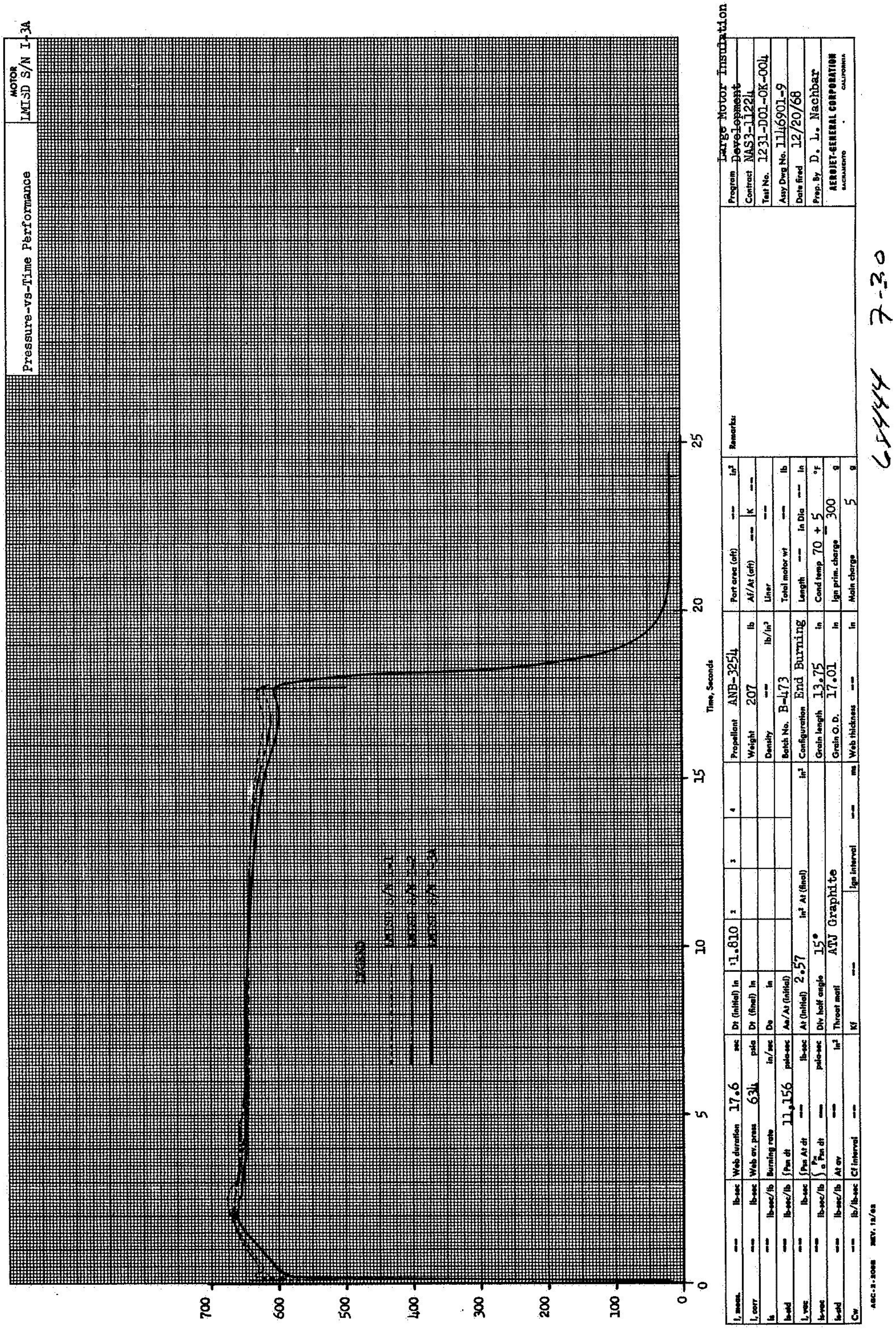
I, meas. -- lb-sec	Web duration 17.7 sec	Dt (initial) in 1.810	2	3	4	Propellant ANB-3254	Port area (aft) -- in²	Remarks:
I, corr -- lb-sec	Web av. press 640 psia	Dt (final) in				Weight 207 lb	Af/At (aft) -- K --	
Is -- lb-sec/lb	Burning rate in/sec	De in				Density -- lb/in³	Liner --	
Is-std -- lb-sec/lb	∫Psn dt 11,350 psia-sec	Ae/At (initial)				Batch No. B-473	Total motor wt -- lb	
I, vac -- lb-sec	∫Psn At dt -- lb-sec	At (initial) 2.57 in²	At (final) in²			Configuration End Burning	Length -- in Dia -- in	
Is-vac -- lb-sec/lb	$\int_0^{P_{so}}$ Psn dt -- psia-sec	Div half angle 15°				Grain length 13.75 in	Cond temp 70 + 5 °F	
Is-std -- lb-sec/lb	At av -- in²	Throat matl ATJ Graphite				Grain O. D. 17.01 in	Ign prim. charge 300 g	
Cw -- lb/lb-sec	Cf interval --	Kf --	Ign interval -- ms			Web thickness in	Main charge 5 g	

Program	Large Motor Insulation Development
Contract	NAS3-11224
Test No.	1231-D01-OK-002
Assy Dwg No.	1146901-9
Date fired	10/31/68
Prep. By	D. L. Nachbar
AEROJET-GENERAL CORPORATION SACRAMENTO · CALIFORNIA	

AGC-3-3098 REV. 12/62

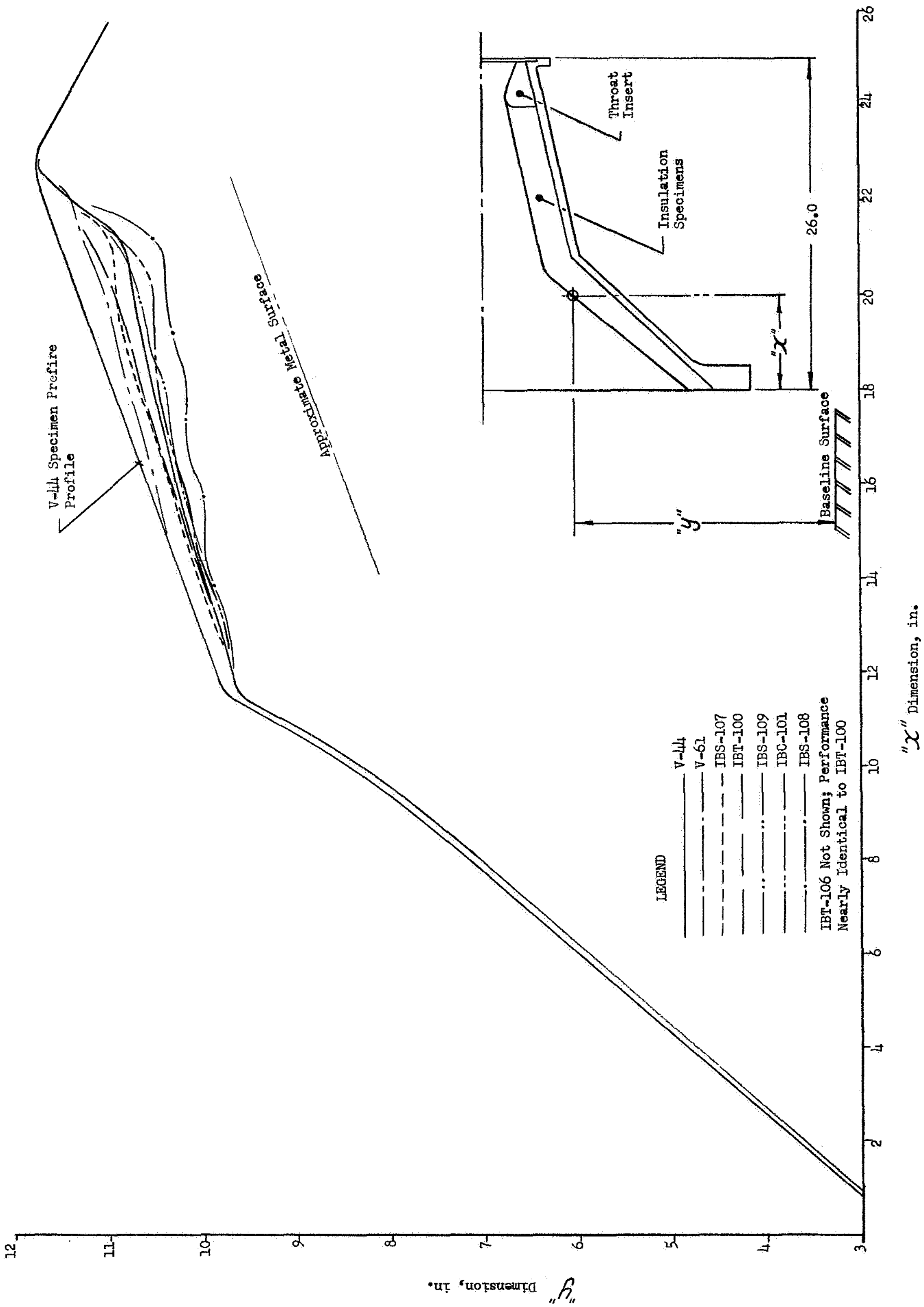
Pressure-vs-Time Performance, Motor S/N I-2

Figure 29



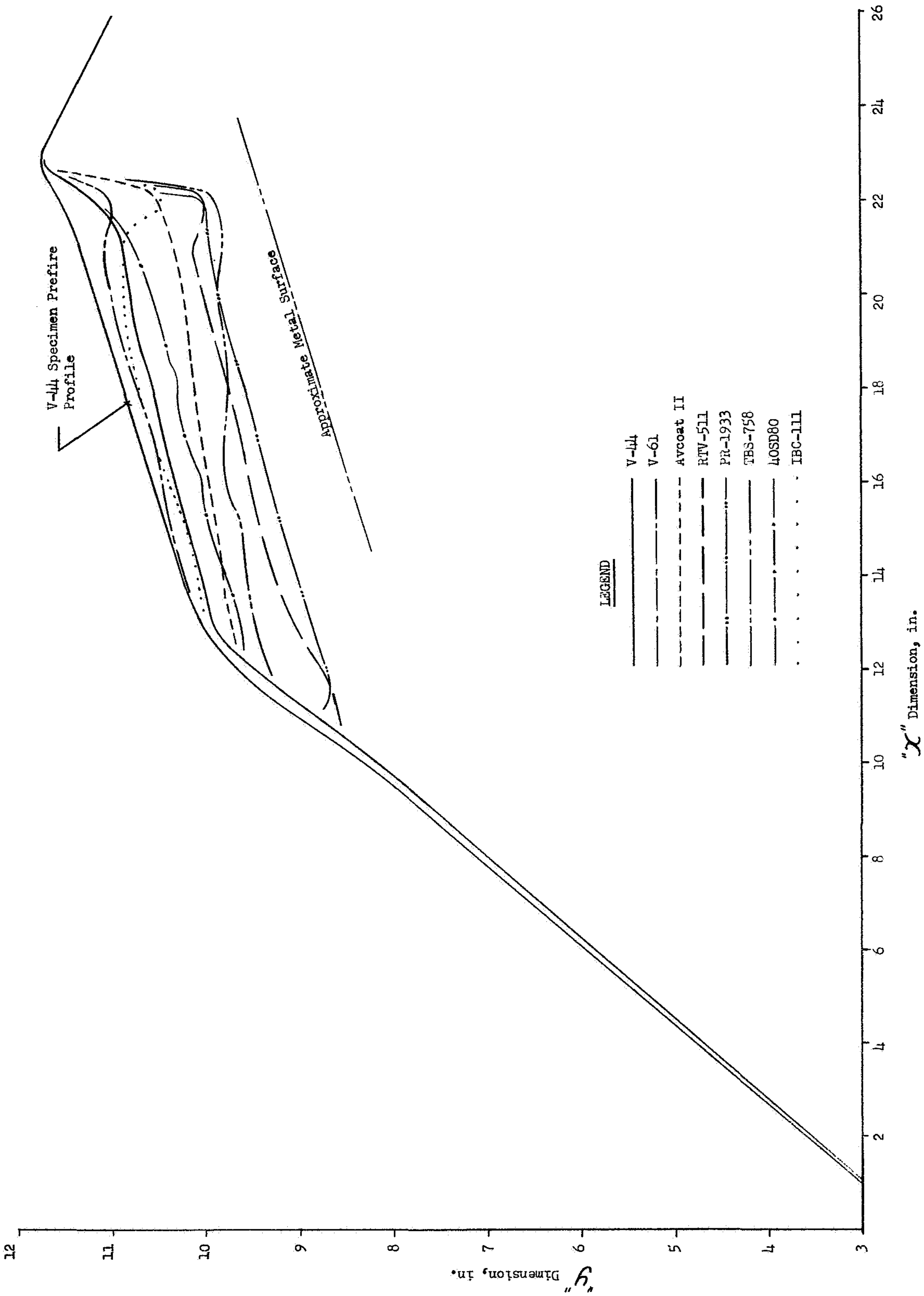
Pressure-vs-Time Performance, Motor S/N I-3A

Figure 30



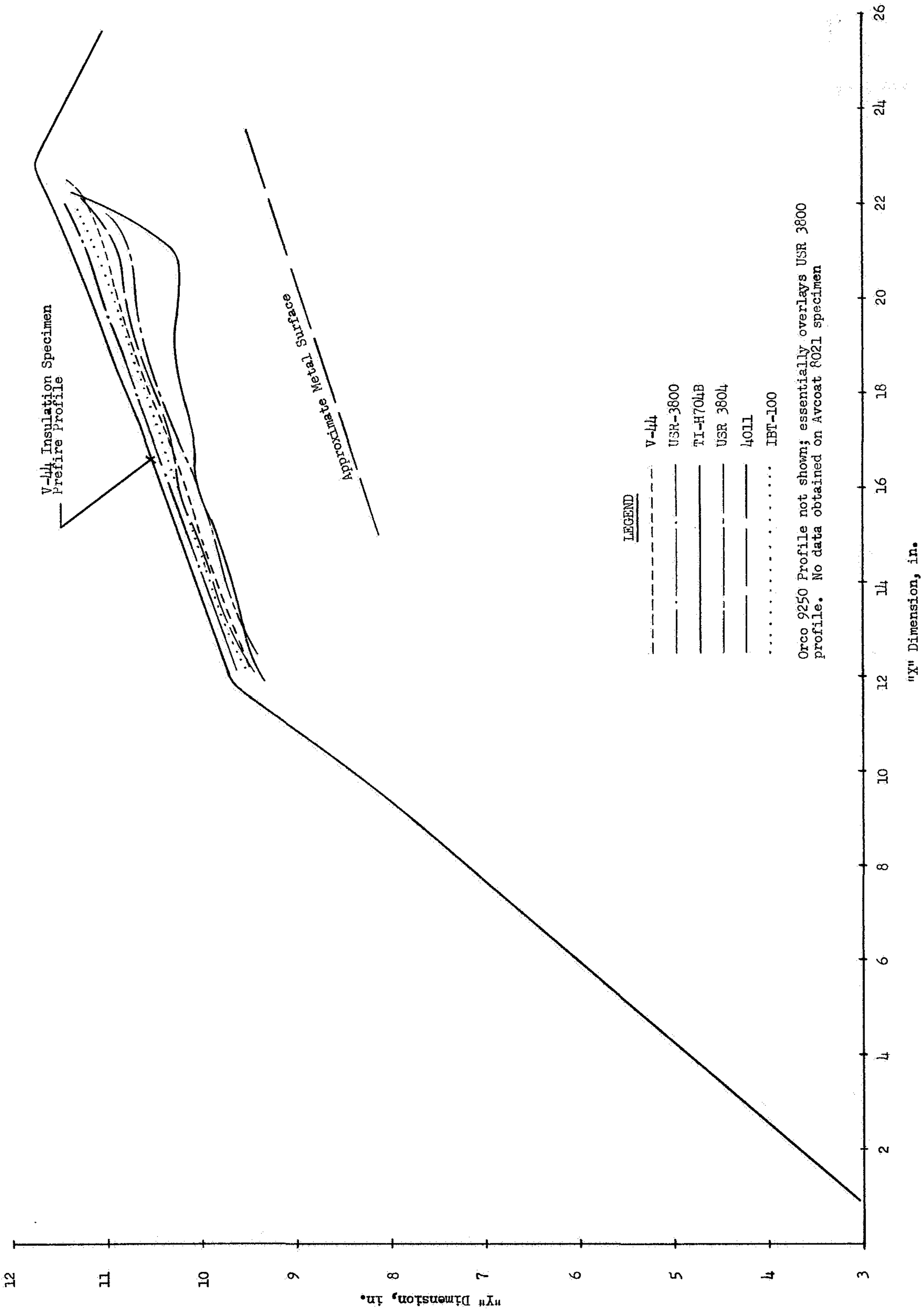
Summary of Insulation Specimen Posttest Profiles, Motor S/N I-1

Figure 31



Summary of Insulation Specimen Posttest Profiles, Motor S/N I-2

Figure 32



Summary of Insulation Specimen Posttest Profiles, Motor S/N I-3A

Figure 33

	LOCATIONS														
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Max. (2)
0°: V-44																
Initial Mach No.	.57	.38	.26	.21	.16	.14	.11	.10	.09	.08	.06	.05	.01	Stag	Stag	-
Thickness Loss	0.26	0.57	0.57	0.49	0.41	0.34	0.30	0.24	0.22	0.21	0.15	0.08	0.08	0.08	0.08	0.65
TLR, in/sec (1)	-	.032	.032	.028	.023	.019	.017	.014	.013	.012	.009	.005	.005	.005	.005	.037
45°: IBS-108																
Initial Mach No.	.49	.31	.24	.17	.14	.11	.10	.09	.08	.06	.05	.02	.01	-	-	-
Thickness Loss	0.14	0.84	0.95	0.81	0.74	0.56	0.51	0.41	0.29	0.31	0.23	0.12	0.06	0.07	0.08	1.00
TLR	-	.048	.054	.046	.042	.032	.029	.023	.016	.018	.013	.007	.004	.004	.005	.057
90°: V-61																
Initial Mach No.	.49	.31	.24	.07	.04	.11	.10	.09	.08	.06	.05	.02	.01	-	-	-
Thickness Loss	0.31	0.25	0.26	0.19	0.16	0.14	0.09	0	0	0	0.02	0.15	0.08	0.06	0.05	0.31
TLR	-	.014	.015	.011	.009	.008	.005	-	-	-	.001	.008	.005	.004	.004	.018
135°: IBS-107																
Initial Mach No.	.42	.28	.20	.16	.14	.11	.10	.09	.08	.06	.05	.02	.01	-	-	-
Thickness Loss	0.17	0.45	0.30	0.20	0.20	0.20	0.18	0.15	0.13	0.14	0.19	0.17	0.08	0.07	0.05	0.45
TLR	-	.026	.017	.011	.011	.011	.010	.008	.007	.008	.001	.009	.005	.005	.004	.026
180°: IBT-100																
Initial Mach No.	.46	.30	.21	.17	.14	.11	.10	.09	.08	.06	.05	.02	.01	-	-	-
Thickness Loss	0.25	0.31	0.31	0.32	0.30	0.23	0.21	0.17	0.17	0.22	0.16	0.10	0.08	0.08	0.09	0.31
TLR	-	.018	.018	.018	.017	.013	.012	.009	.009	.003	.009	.006	.005	.005	.005	.018
215°: IBC-101																
Initial Mach No.	.46	.30	.21	.17	.14	.11	.10	.09	.08	.06	.05	.02	.01	-	-	-
Thickness Loss	0.18	0.59	0.75	0.60	0.45	0.36	0.34	0.27	0.27	0.25	0.23	0.14	0.13	0.13	0.13	0.77
TLR	-	.034	.042	.034	.026	.021	.019	.015	.015	.014	.013	.008	.007	.007	.007	.044
270°: IBT-106																
Initial Mach No.	.57	.38	.26	.21	.16	.14	.11	.10	.09	.08	.06	.05	.01	-	-	-
Thickness Loss	0.21	0.52	0.31	0.30	0.31	0.28	0.28	0.30	0.30	0.28	0.27	0.10	0.12	0.12	0.10	0.52
TLR	-	.030	.018	.017	.018	.016	.016	.017	.017	.016	.016	.005	.007	.007	.006	.030
315°: IBS-109																
Initial Mach No.	.42	.28	.20	.16	.14	.11	.10	.09	.08	.06	.05	.02	.01	-	-	-
Thickness Loss	0.18	0.48	0.52	0.48	0.48	0.37	0.30	0.30	0.29	0.27	0.22	0.09	0.09	0.08	0.08	0.55
TLR	-	.027	.030	.027	.027	.021	.017	.017	.017	.015	.013	.005	.005	.005	.005	.030

NOTES: (1) TLR, thickness loss rate $= \frac{\text{Thickness Loss}}{\text{Web Duration}}$; web duration was 17.6 sec.

(2) Maximum ablation occurred between position 9 and 10.

Summary of Insulation Specimen Erosion Data, Motor S/N I-1

Figure 34

	LOCATIONS															
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Max. (2)
0°: V-44																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.25	0.47	0.37	0.31	0.30	0.24	0.23	0.21	0.20	0.14	0.12	0.12	0.09	0.09	0.05	0.47
TLR (1)	-	.027	.021	.018	.017	.014	.013	.012	.011	.008	.007	.007	.005	.005	.003	.027
45°: 40SD-80																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.24	0.53	0.62	0.61	0.58	0.41	0.46	0.41	0.41	0.41	0.19	0.11	0.11	0.10	0.09	0.62
TLR	-	.030	.035	.035	.033	.023	.026	.023	.023	.023	.011	.006	.006	.005	.005	.035
90°: V-61																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.40	0.29	0.17	0.12	0.12	0.14	0.08	0.05	0.05	0.04	0.04	0.05	0	0.04	0.05	0.48
TLR	-	.016	.010	.007	.007	.008	.004	.003	.003	.002	.002	.003	0	.002	.003	.027
135°: Avcoat II																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.50	1.00	1.00	0.93	0.79	0.67	0.58	0.52	0.46	0.39	0.25	0.07	0.10	0.09	0.09	1.00
TLR	-	.057	.057	.053	.045	.038	.033	.029	.026	.022	.015	.004	.006	.005	.005	.057
180°: RTV-511																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.55	1.43	1.16	1.10	1.06	1.04	1.00	0.94	0.88	0.87	0.95	0.75	0.15	0.12	0.10	1.43
TLR	-	.081	.066	.062	.060	.059	.057	.054	.050	.049	.055	.042	.008	.007	.006	.081
225°: PR-1933																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.51	1.45	1.33	1.23	1.21	1.19	1.16	1.14	1.11	1.10	1.09	0.90	0.50	0.21	0.16	1.45
TLR	-	.082	.075	.070	.068	.067	.066	.064	.063	.062	.062	.050	.028	.012	.009	.082
270°: TBS-758																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.60	1.58	1.48	1.28	1.18	0.98	0.80	0.72	0.70	0.58	0.49	0.21	0.10	0.05	-	1.58
TLR	-	.089	.084	.072	.067	.055	.045	.041	.040	.033	.028	.012	.006	.003	-	.089
315°: IBC-111																
Initial Mach No.	.43	.30	.23	.19	.15	.12	.11	.10	.08	.05	.04	.03	.01	-	-	-
Thickness Loss	0.52	0.70	0.35	0.22	0.18	0.14	0.16	0.18	0.14	0.11	0.20	0.14	0.08	0.05	0.02	1.05
TLR	-	.040	.020	.013	.010	.008	.009	.010	.008	.006	.012	.088	.005	.003	.001	.059

NOTES: (1) TLR, thickness loss rate $= \frac{\text{Thickness Loss}}{\text{Web Duration}}$; web duration was 17.7 sec

(2) Maximum ablation occurred between position 9 and 10.

Summary of Insulation Specimen Erosion Data, Motor S/N I-2

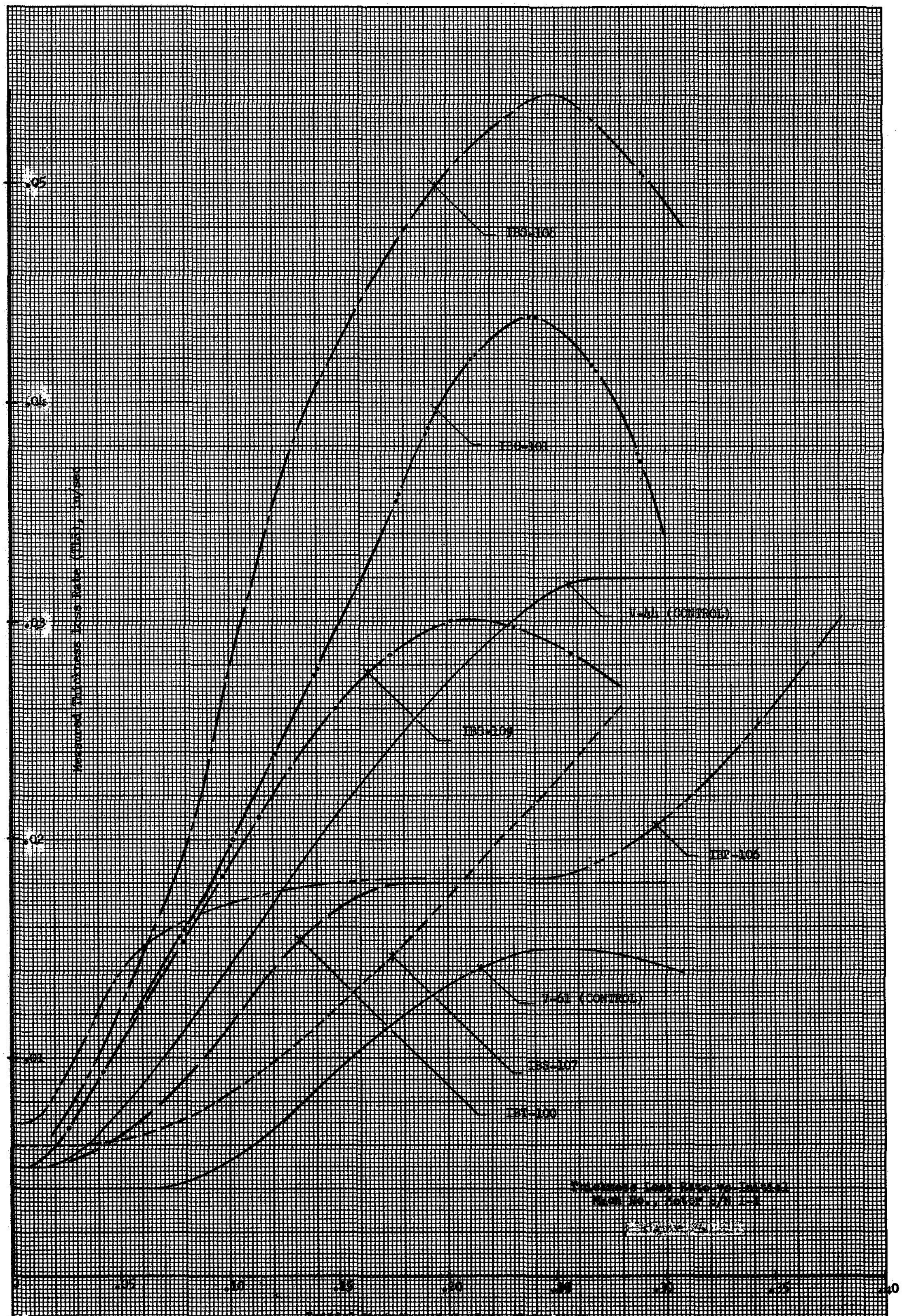
Figure 35

	LOCATIONS															
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Max. [3]
0°: V-44																
Initial Mach No.	.44	.31	.22	.18	.04	.12	.10	.09	.08	.07	.06	.04	.02	-	-	-
Thickness Loss	0.36	0.36	0.30	0.26	0.23	0.24	0.24	0.22	0.21	0.21	0.21	0.10	0.09	0.08	0.06	0.38
TLR [1]	0.021	0.021	0.017	0.015	0.013	0.014	0.014	0.012	0.012	0.012	0.012	0.006	0.005	0.005	0.003	0.022
45°: V-61/TI-H704B [2]																
Initial Mach No.	.37	.25	.18	.14	.12	.10	.09	.08	.07	.06	.05	.04	.02	-	-	-
Thickness Loss	0.20	0.70	0.85	0.52	0.46	0.43	0.30	0.31	0.30	0.26	0.20	0.10	0.05	0.08	0.05	0.92
TLR	0.011	0.040	0.049	0.030	0.026	0.024	0.017	0.018	0.017	0.015	0.011	0.006	0.003	0.005	0.003	0.052
90°: USR-3800																
Initial Mach No.	.41	.28	.21	.17	.14	1.2	.10	.08	.07	0.6	0.5	0.4	.02	-	-	-
Thickness Loss	0.11	0.11	0.10	0.10	0.10	0.08	0.08	0.08	0.08	0.07	0.07	0.04	0.04	0.04	0.08	0.11
TLR	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.004	0.004	0.002	0.002	0.002	0.005	0.006
135°: Orco 9250																
Initial Mach No.	.44	.31	.22	.18	.14	.12	.10	.09	.08	.07	.06	.04	.02	-	-	-
Thickness Loss	0.25	0.20	0.12	0.15	0.10	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.25
TLR	0.011	0.016	0.004	0.011	0.010	0.010	0.009	0.010	0.009	0.009	0.008	0.005	0.005	0.005	0.003	0.016
180°: IBT-100																
Initial Mach No.	.41	.31	.22	.17	.14	.12	.10	.09	.08	.07	.06	.04	.02	-	-	-
Thickness Loss	0.20	0.28	0.25	0.20	0..8	0.17	0.15	0.17	0.16	0.15	0.14	0.09	0.08	0.08	0.05	0.28
TLR	0.011	0.016	0.014	0.011	0.010	0.010	0.009	0.010	0.009	0.009	0.008	0.005	0.005	0.005	0.003	0.016
225°: 4011																
Initial Mach No.	.41	.28	.21	.17	.14	.12	.10	.08	.07	.06	.05	.04	.02	-	-	-
Thickness Loss	0.25	0.42	0.30	0.25	0.24	0.22	0.15	0.16	0.15	0.15	0.13	0.08	0.08	0.10	C.10	0.42
TLR	0.014	0.024	0.017	0.014	0.014	0.013	0.009	0.009	0.009	0.009	0.007	0.005	0.005	0.006	0.006	0.024
270°: Avcoat 8021																
Initial Mach No.	.44	.31	.22	.18	.14	.12	.10	.09	.08	.07	.06	.04	.02	-	-	-
Thickness Loss	No usable data											0.15	0.12	0.15	0.16	-
TLR	-	-	-	-	-	-	-	-	-	-	-	0.009	0.007	0.009	0.009	-

NOTES:
[1] TLR, thickness loss rate = $\frac{\text{Thickness Loss}}{\text{Web Duration}}$; web duration was 17.6 sec.
[2] V-61 from Locations 18 to 22; TI-H704B from Locations 8 to 18.
[3] Maximum ablation occurred between locations 9 and 10.

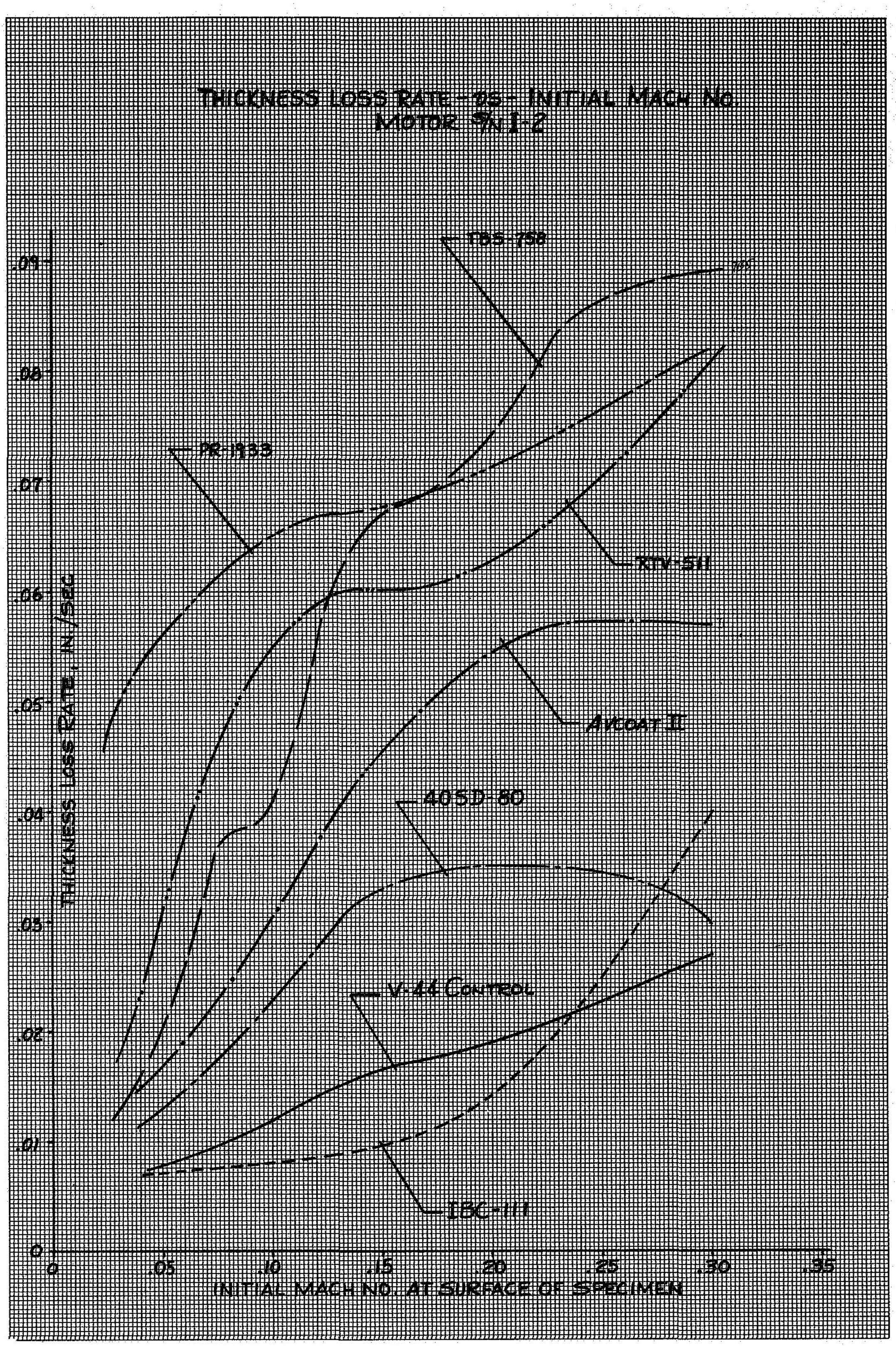
Summary of Insulation Specimen Erosion Data, Motor S/N I-3A

Figure 36



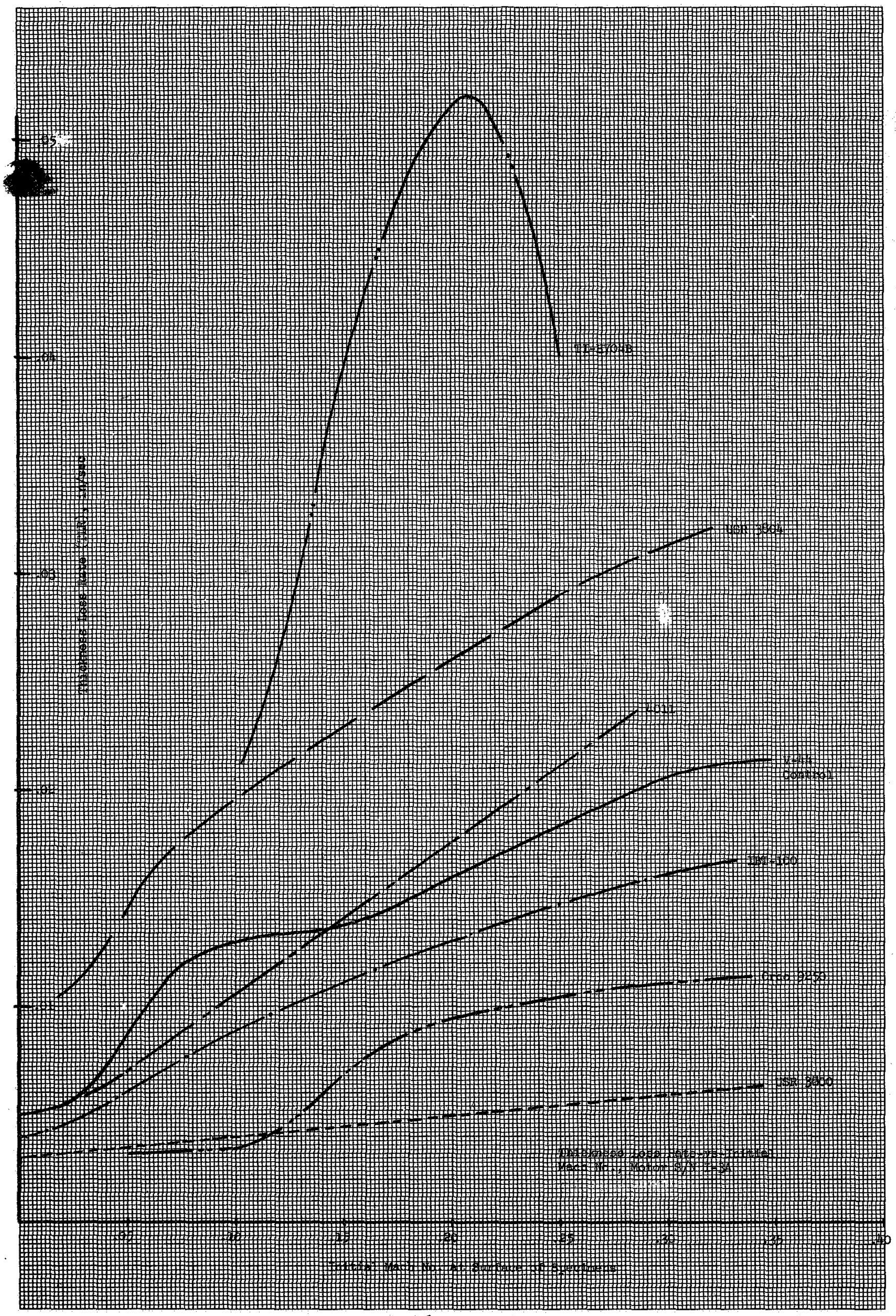
Thickness Loss Rate-vs-Initial Mach Number, Motor S/N I-1

Figure 37



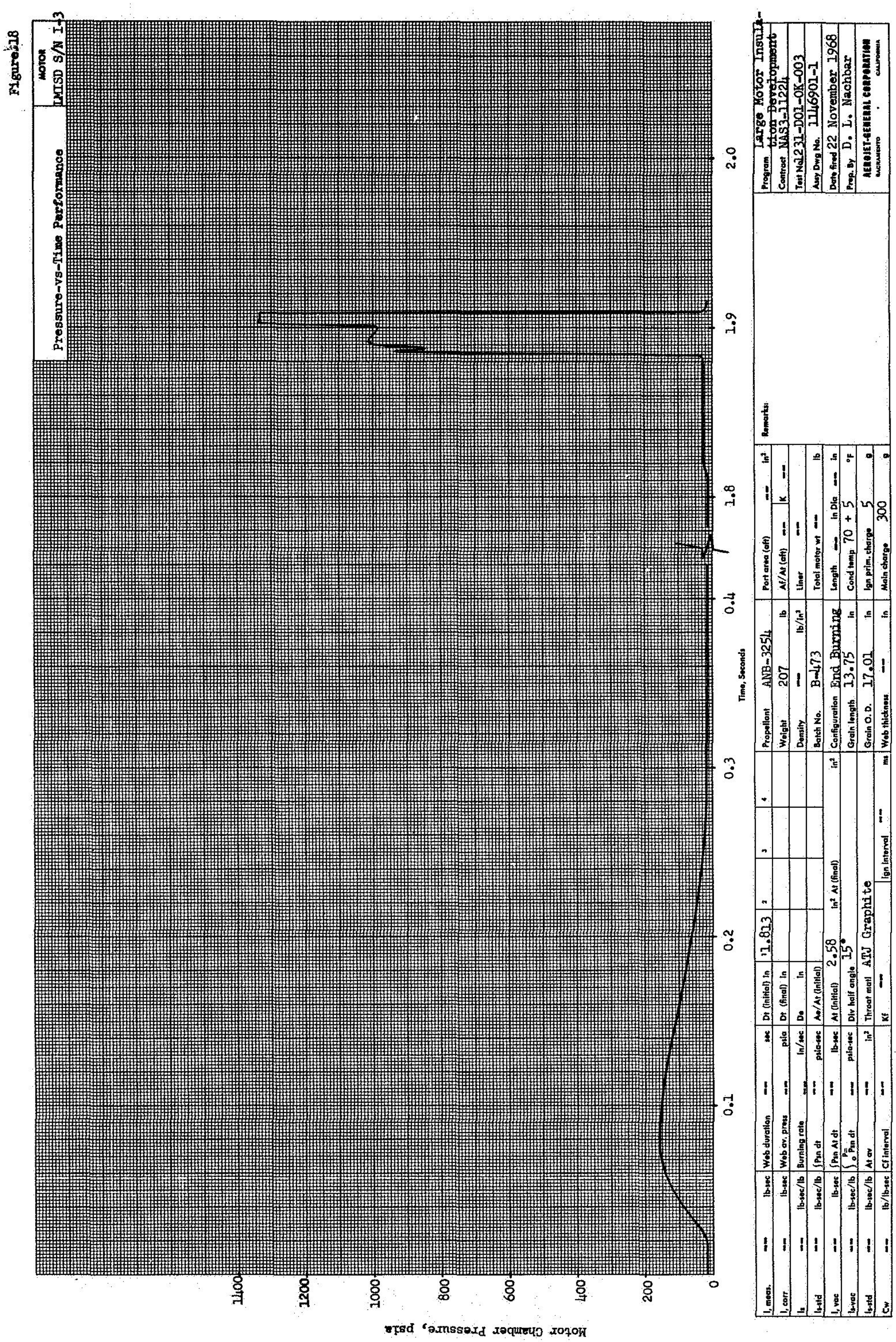
Thickness Loss Rate-vs-Initial Mach Number, Motor S/N I-2

Figure 38



Thickness Loss Rate-vs-Initial Mach Number, Motor S/N I-3A

Figure 39



Pressure-vs-Time Performance, Motor S/N I-3

	Erosion	Material Cost	$/lb for 25,000 lb [1]	Density	gm/cc @ 100°F	Heat of Combustion (Thermal Properties)	cal/gm	Heat Capacity (Thermal Properties)	cal/gm °C @ 150°F	Thermal Conductivity (Thermal Properties)	Btu-in/hr-ft^2-°F @ 74°F	Moisture Absorption	Weight Gain @ 50% RH, %	Weight Gain @ 90% RH, %
1.	USR 3800	Castable Carbon	0.90	Avcoat II	1.102	Avcoat II	9934	Avcoat II	0.507	USR-3800	0.783	IBS-108	0.30	0.59
2.	Orco 9250	IBT-106	0.97	USR-3800	1.146	IBS-107	8592	Avcoat 8021	0.453	V-61	1.170	TI-H704B	0.30	1.78
3.	V-61 (Control)	IBT-100	1.05	RTV-511	1.169	IBS-108	8530	USR-3800	0.432	Avcoat II	1.263	IBS-109	0.31	0.60
4.	IBT-100	IBC-101	1.05	Avcoat 8021	1.192	IBS-109	8267	V-4011	0.428	IBS-107	1.366	IBS-107	0.32	0.65
5.	IBS-107	IBS-108	1.10	USR-3804	1.199	Avcoat 8021	8434	V-44	0.407	IBS-101	1.452	IBC-111	0.32	0.68
6.	IBC-111	IBS-109	1.10	V-4011	1.200	IBC-101	7724	IBS-107	0.389	RTV-511	1.486	IBT-100	0.34	0.62
7.	IBT-106	USR-3800	1.40	IBS-107	1.225	V-4011	7199	IBS-108	0.389	IBT-106	1.519	USR-3804	0.36	0.77
8.	V-44 (Control)	USR-3804	1.40	IBS-109	1.235	USR-3804	7053	IBS-109	0.385	40SD-80	1.520	IBT-106	0.39	0.73
9.	IBS-109	Orco 9250	1.46	IBS-108	1.253	IBT-106	6931	V-61	0.382	IBT-100	1.529	IBC-101	0.42	0.84
10.	V-4011	Avcoat II	1.55	Orco 9250	1.259	TI-H704B	6916	USR-3804	0.375	Avcoat 8021	1.591	40SD-80	0.49	1.03
11.	USR-3804	TI-H704B	1.87	V-44	1.296	USR-3800	6474	Orco 9250	0.373	USR-3804	1.686	Avcoat 8021	0.94	1.63
12.	40SD-80	Avcoat 8021	1.89	V-61	1.308	IBT-100	6151	TI-H704B	0.364	PR-1933	1.864	Orco 9250	1.01	1.80
13.	IBC-101	IBC-111	1.90	40SD-80	1.312	Orco 9250	5897	IBC-101	0.363	IBS-108	1.825	V-44	1.13	2.40
14.	TI-H704B	IBS-107	2.00	IBC-101	1.329	V-44	5822	IBT-106	0.356	Orco 9250	1.942	USR-3800	1.51	2.60
15.	IBS-108	40SD-80	2.80	TI-H704B	1.334	40SD-80	5772	RTV-511	0.346	V-44	1.955	V-61	1.65	3.12
16.	Avcoat II	V-44	3.19	IBC-111	1.389	V-61	5441	40SD-80	0.337	V-4011	2.184	RTV-511, PR-1933, 93-104, Avcoat II, Castable Carbon, TBS-758; not tested.		
17.	RTV-511	V-61	3.48	IBT-100	1.390	RTV-511	5434	IBT-100	0.374	IBS-109	2.254			
18.	PR-1933	PR-1933	5.00	PR-1933	1.416	PR-1933	4412	PR-1933	0.320	93-104	2.265			
19.	TBS-758	RTV-511	5.55	IBT-106	1.423	93-104	4182	93-104	0.288	TI-H704B	3.358			
20.	Avcoat 8021; no data obtained. Castable Carbon and 93-104; not tested	93-104	6.00	93-104	1.431	Castable Carbon, IBC-111, TBS-758; not tested.		Castable Carbon	0.216	Castable Carbon	16.491			
21.		V-4011	6.25	Castable Carbon	1.674			IBC-111, TBS-758; not tested.		IBC-111, TBS-578; not tested.				

[1] Raw material, plus mixing and curing cost.

Relative Listing of Materials with Respect to Erosion, Cost, Physical, Thermal, Chemical, and Adhesive Properties

Figure 41, Sheet 1 of 2

Mechanical Properties △1

Acceptable	Marginal	Unacceptable
V-44	93-104	RTV-511
Orco 9250	IBS-108	
USR-3800	TBS-758	
USR-3804		
V-61		
IBT-100		
IBT-106		
TI-H704B		
V-4011		
IBC-101		
IBC-111		
40SD-80		
Avcoat 8021		
IBS-107		
IBS-109		
Avcoat II		
PR-1933		

Ambient Pot Life △2

Acceptable	Marginal	Unacceptable
IBT-100	93-104	V-61
IBT-106	40SD-80	V-4011
TI-H704B	TBS-758	
IBC-101	Avcoat II	
IBC-111	PR-1933	
RTV-511		
IBS-107		
IBS-108		
IBS-109		

Bond Line Tensile/Shear △3

Acceptable	Marginal	Unacceptable
V-44	IBS-108 △4	V-4011
Orco 9250	IBS-109 △4	93-104
USR-3800	Avcoat II	RTV-511
USR-3804	IBS-107 △4	PR 1933
V-61		
IBT-100 △4		
IBT-106 △4		
TI-H704B		
IBC-101 △4		
IBC-111 △4		
40SD-80		
Avcoat 8021		

Bond Line Tensile/Shear After Moisture Exposure △3

Acceptable	Marginal	Unacceptable
V-44	IBT-100 △4	△5
Orco 9250	IBT-106 △4	
USR-3800	IBC-101 △4	
USR-3804	IBC-111 △4	
V-61	IBS-107 △4	
40SD-80	IBS-109 △4	
Avcoat 8021	IBS-108 △4	

NOTES:

△1 Acceptable: Tensile strength > 120 psi, elongation at maximum tensile strength > 0.75%.
Marginal: Tensile strength < 120 psi, but > 90 psi.
Unacceptable: Tensile strength < 90 psi.

△2 Acceptable: Pot Life > 4 hrs.
Marginal: Pot Life < 4 hrs, but > 1 hr.
Unacceptable: Pot Life < 1 hr.
Not applicable to pressure-cured materials; V-44, Orco 9250, USR-3800, USR-3804, Avcoat 8021.

△3 Acceptable: Tensile/Shear > 100 psi; failure in propellant.
Marginal: Tensile/Shear < 100 psi; but > 50 psi; failure at insulation-liner-propellant interface.
Unacceptable: Tensile/Shear < 50 psi.

△4 No SD850-2 liner used with these specimens.

△5 Materials which were unacceptable in the original bond line tensile/shear test were not subjected to moisture absorption tests.

Relative Listing of Materials with Respect to Erosion, Cost, Physical, Thermal, Chemical, and Adhesive Properties

Department 3800 Propel. Development, Line 5		Department 0720 Material Technology		Project	
Material	Rating (1)	Material	Rating (1)	Material	Rating (2)
IBT-100	970	IBC-101	847	USR 3800	47
IBT-106	955	IBT-100	846	IBS-107	61
IBS-109	908	IBT-106	840	IBS-109	70
IBC-111	885	IBC-111	830	Orco 9250	72
IBS-107	885	IBS-107	732	IBT-100	75
IBC-101	870	4011	704	IBT-106	75
IBS-108	847	IBS-109	703	IBC-111	81
TI-H704B	783	IBS-108	702	IBC-101	83
Orco 9250	700	Avcoat II	692	Avcoat II	90
USR 3800	615	40SD-80	686	TI-H704B	108
40SD-80	585	V-61	664	V-44	108
USR 3804	585	Orco 9250	660	40SD-80	110
Avcoat II	570	USR 3800	649	USR 3804	112
V-44	570	TI-H704B	641	IBS-108	120
V-61	520	USR 3804	593	V-61	130
4011	480	V-44	576	4011	Eliminated

(1) Rating based on 10 points for best material in each category considered multiplied by the weighting factor.

(2) Rating based on relative standing of each material in each category considered.

Summary of Material Ratings

Figure 42

Material	Supplier
Pressure-Cured Class	
Gen-Gard V-44 (Control)	General Tire & Rubber Co.
USR 3800 [1]	Uniroyal, Inc.
Trowelable Class	
IBT-100	Aerojet-General Corp.
IBT-106	Aerojet-General Corp.
TI-H704B [2]	Thiokol Chemical Corp.
Castable Class	
IBC-101	Aerojet-General Corp.
IBC-111	Aerojet-General Corp.
40SD-80	American Poly-Therm Co.
Sprayable Class	
IBS-107	Aerojet-General Corp.
IBS-109	Aerojet-General Corp.
Avcoat II	Avco Corp.
Back-Up Materials	
[1] Orco 9250	Ohio Rubber Co.
[2] Avcoat 8021	Avco Corp.

[1] Orco 9250 was the back-up material for USR-3800

[2] Avcoat 8021 was the back-up material for TI-H704B

Recommended Materials for Further
Evaluation in Tasks II and III

Figure 43

	TASK II	TASK III
PRESSURE-CURED		
V-44 (Control)	No demonstration	5 motor tests
USR 3800 [1]	No demonstration	1 motor test
TROWELABLE		
IBT-100	1 demonstration forward/aft head insulator	1 motor test
IBT-106	1 demonstration	1 motor test
TI-H704B [2]	1 demonstration	1 motor test
CASTABLE		
IBC-111	1 demonstration	1 motor test
IBC-101	No demonstration	1 motor test
40SD-80	1 demonstration	1 motor test
SPRAYABLE		
IBS-107	2 demonstrations	1 motor test
IBS-109	2 demonstrations	1 motor test
Avcoat II [3]	1 demonstration	1 motor test

[1] Orco 9250 alternate.

[2] Avcoat 8021 alternate.

[3] Use of Avcoat II dependent on outcome of bond strength remeasurement.

Recommended Tasks II and III Material Selection and Evaluation Plan

Figure 44

APPENDIX I

TEST PROCEDURES FOR MATERIAL PROPERTY MEASUREMENTS

I. COMPOSITE TENSILE STRENGTH AND MODULUS

The mechanical properties of each of the 20 materials to be screened were evaluated using standard JANAF dumbbell specimens tested on an Instron machine according to AGC Method 3431. The specimens were prepared by die-cutting from a nominal 0.5-in.-thick piece of insulation material. In the case of the castable-sprayable-trowelable materials, the specimens were prepared by casting into Instron bar molds or into 0.5-in.-thick slabs from which the bars were cut. Triplicate specimens were tested at a strain rate of 2.0 in./min.

II. DENSITY

The density of insulation materials at 100, 200, and 300°F were measured by the liquid displacement method. A Dow Corning 710 silicone liquid that remains stable at 500°F was used as the displacement fluid. The test apparatus was constructed to permit the heated sample to be weighed in air; then the sample was transferred and immersed in heated Dow Corning 710 fluid where it was weighed again. The volume and weight of the test sample were obtained at the desired test temperature; material density was calculated from this data.

III. POT LIFE AND VISCOSITY

The pot life and viscosity of the highly viscous trowelable materials were determined from time-viscosity curves using the extrusion tube rheometer designed by Aerojet. Samples were loaded into a temperature-controlled reservoir and pressurized to produce vertical flow through a thermostated discharge tube. The available discharge tubes were 20 in. long and their inside diameters varied from 0.131 to 0.683 in. Measurements made by using this equipment and a standard calibrating fluid showed that neither complex operating techniques nor special corrections were required to obtain accuracy and reproducibility.

The plot life and viscosity of the less viscous castable and sprayable materials were determined from time-viscosity curves using a rotational viscometer. This viscometer was used to measure the thixotropic breakdown of a sample, and was able to determine the viscosity of the material over a very wide rangeof shear stresses.

The viscosity of each sample was determined at intervals of 10 min. to 3 hours (depending on reactivity) until the end of the pot life was indicated by material gelling.

IV. BOND LINE TENSILE STRENGTH

The bond line tensile and shear strength of the 4130 steel, Fuller 162-Y-22 primer, insulation specimen, SD850-2 liner (if required) and ANB-3254 propellant composite were determined using the double-plate sandwich specimen described in Aerojet Method 3421. The specimens were prepared by bonding the insulation to be tested to steel plates approximately 2.375 in. square. The insulation was lined with SD-850-2 liner (if necessary) and propellant was cast between two plates held parallel in a mold. The cross-section of the composite was approximately 1.75 in.-sq. Then the specimens were stressed to failure in either a tensile or a shear mode (duplicate specimens in each mode) and the failure stress was recorded. The type and location of the failure also was noted. Insulation used in these tests were "as received".

V. WATER ABSORPTION

The moisture absorption and regain characteristics of the insulation materials were determined by drying samples for (24 of each material) of the insulation (approximately 0.080 in. thick) in a 180°F circulating air oven. After constant weight was reached, eight of the samples were removed from the oven and used to prepare specimens for evaluation of bond line tensile and shear strength as described previously in test method IV.

Eight of the samples then were exposed to a controlled relative humidity of 50% at 77°F until constant weight again was achieved. These samples were used to evaluate bond line tensile and shear strength as in IV. The weight gain, weight loss, and bond strength measurements provided an overall assessment of the moisture retention characteristics and effect on bonding of the individual insulation materials. The remaining eight samples were exposed to a controlled 90% relative humidity as described above. These specimens were redried and weighed as described above to determine the amount of the moisture evolved at the higher humidity level.

VI. THERMAL DIFFUSIVITY AND THERMAL CONDUCTIVITY

The flash method was used to determine the thermal diffusivity of insulation material specimens. In this method, a very short pulse of radiant energy was directed at the front of a specimen and the resultant history of the rear surface was recorded. This method, which measured diffusivity from ambient temperature in air up to 1400°F used a resistance furnace to heat the specimen and a thermocouple as the rear-surface temperature detector. Thermal conductivity was calculated from the measured density, specific heat, and diffusivity values.

VII. THERMOGRAVIMETRIC ANALYSIS (TGA)

A thermogravimetric (TGA) balance was used to study the weight loss and temperature as a function of time of insulation samples. The apparatus consisted of an automatic recording balance and a heavy duty furnace. A liner heating rate of 20°C/min. was used up to a maximum temperature of 800°C. Testing was conducted in an argon atmosphere.

VIII. HEAT CAPACITY (SPECIFIC HEAT)

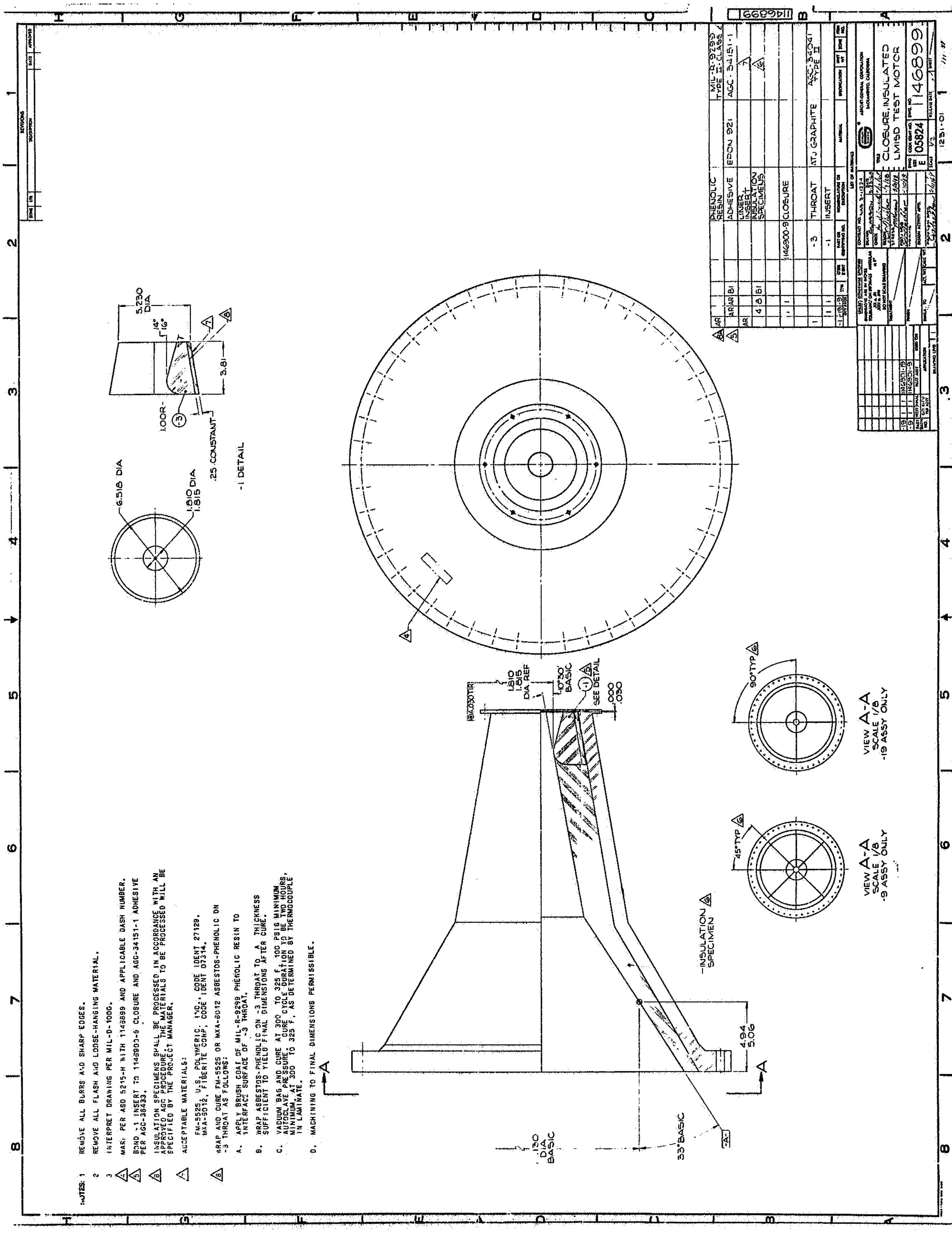
A calorimeter was used to determine the heat capacity of insulation materials. The material samples were heated to the desired temperature with an electric, multiple-tube furnace and dropped into distilled water in the calorimeter. The temperature of the system at equilibrium was observed and used to calculate the material enthalpy. Initially, the calorimeter was calibrated using a known weight of copper or zinc. The mean specific heat was obtained from the slope of the enthalpy (ΔH) temperature curve. Instantaneous specific heats were approximated closely by plotting the slopes of ΔH vs temperature at small intervals along the curve.

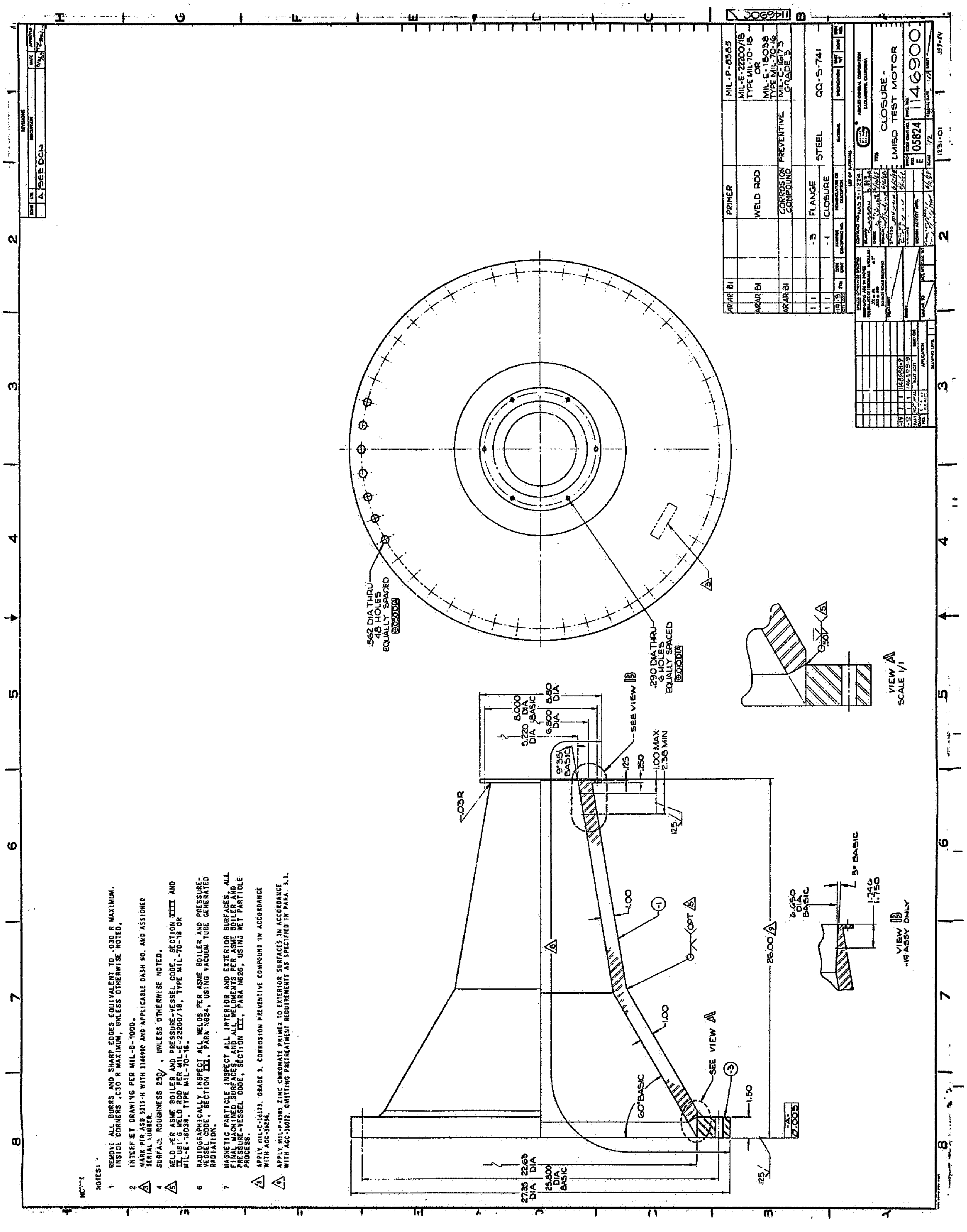
IX. HEAT OF COMBUSTION

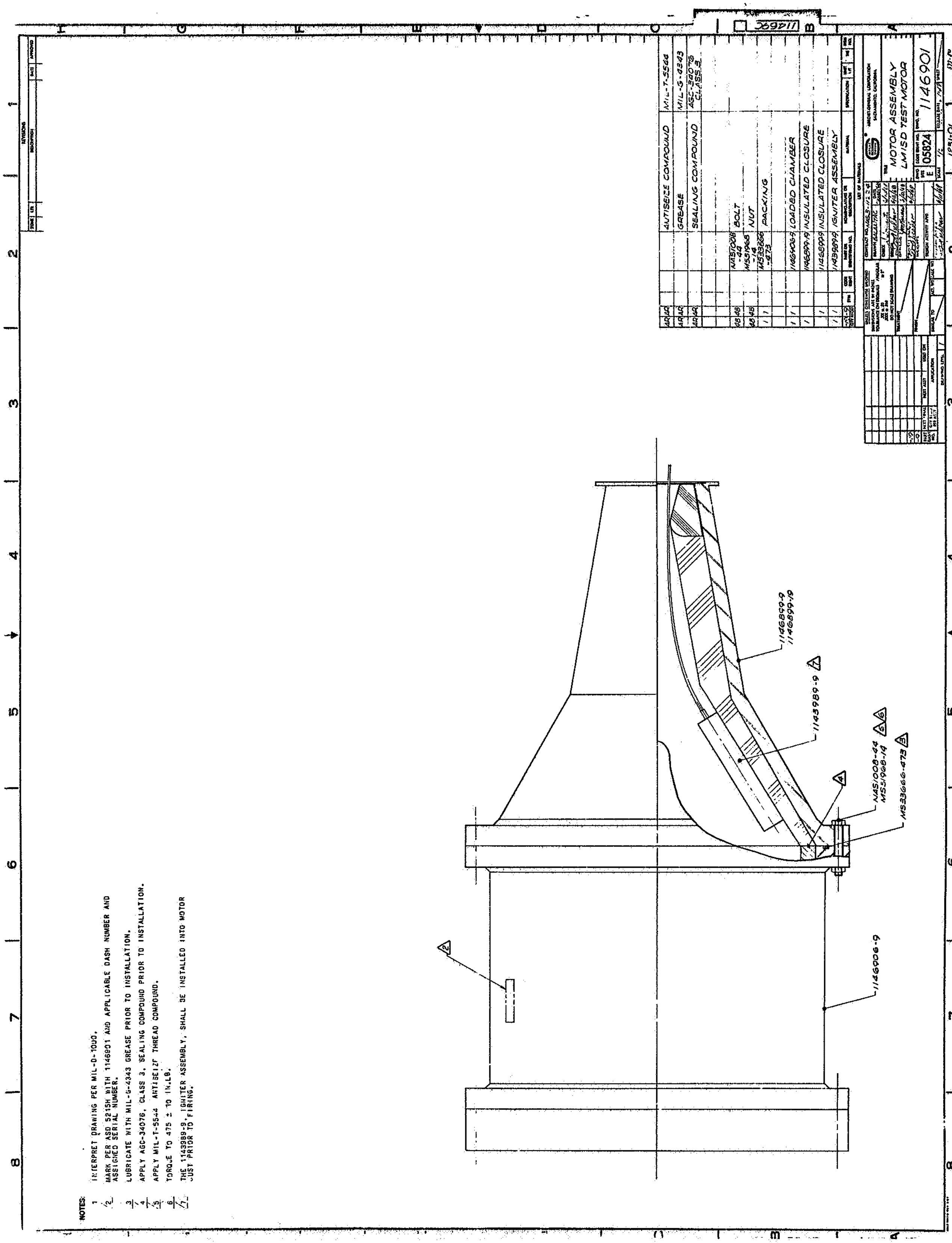
The material heat of combustion was determined by the standard bomb calorimeter technique. A known weight of sample was reacted with oxygen in a "bomb" type of calorimeter and the heat balance at equilibrium was used to calculate the heat of combustion for the material.

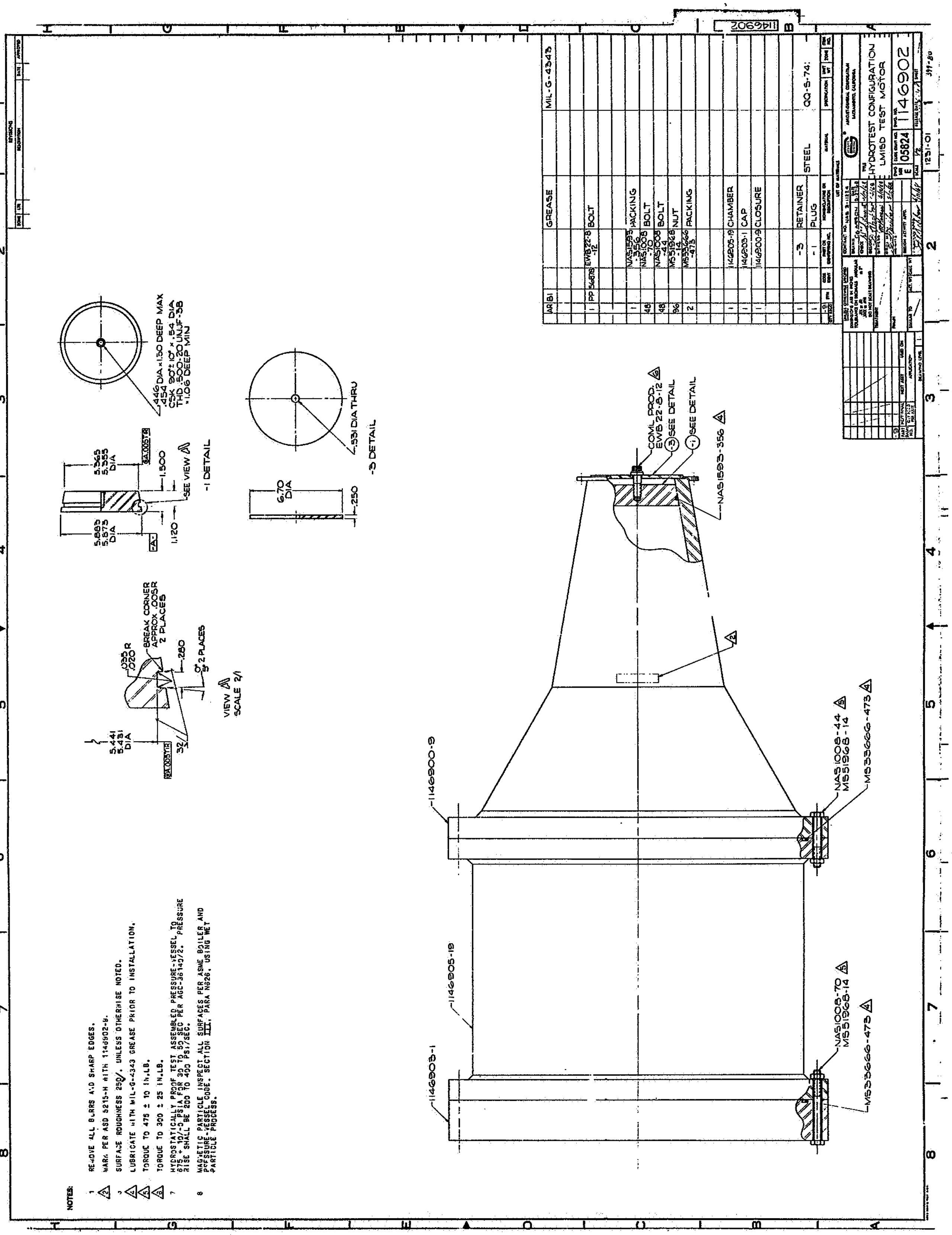
APPENDIX II

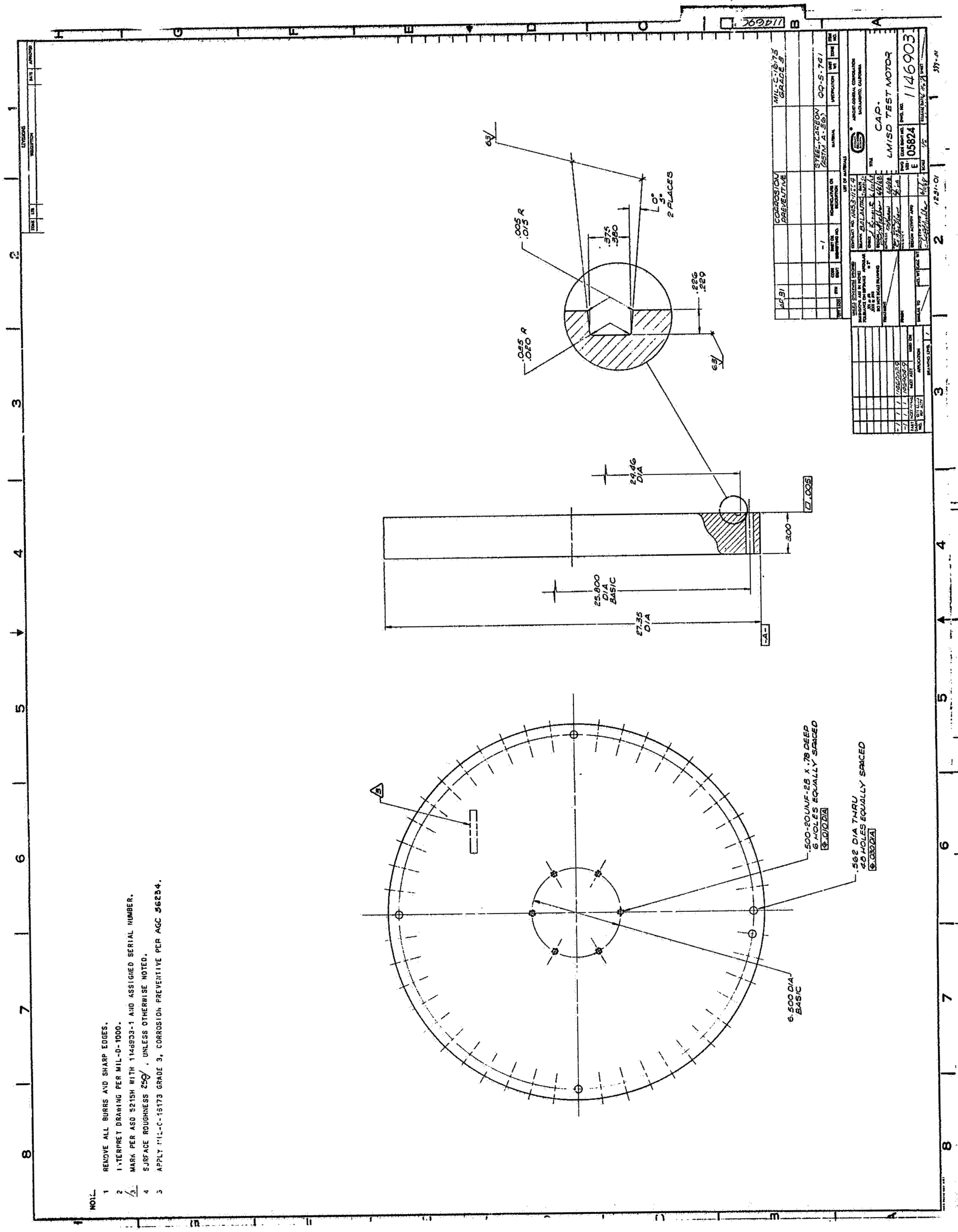
ENGINEERING DRAWINGS FOR LMISD TEST MOTOR

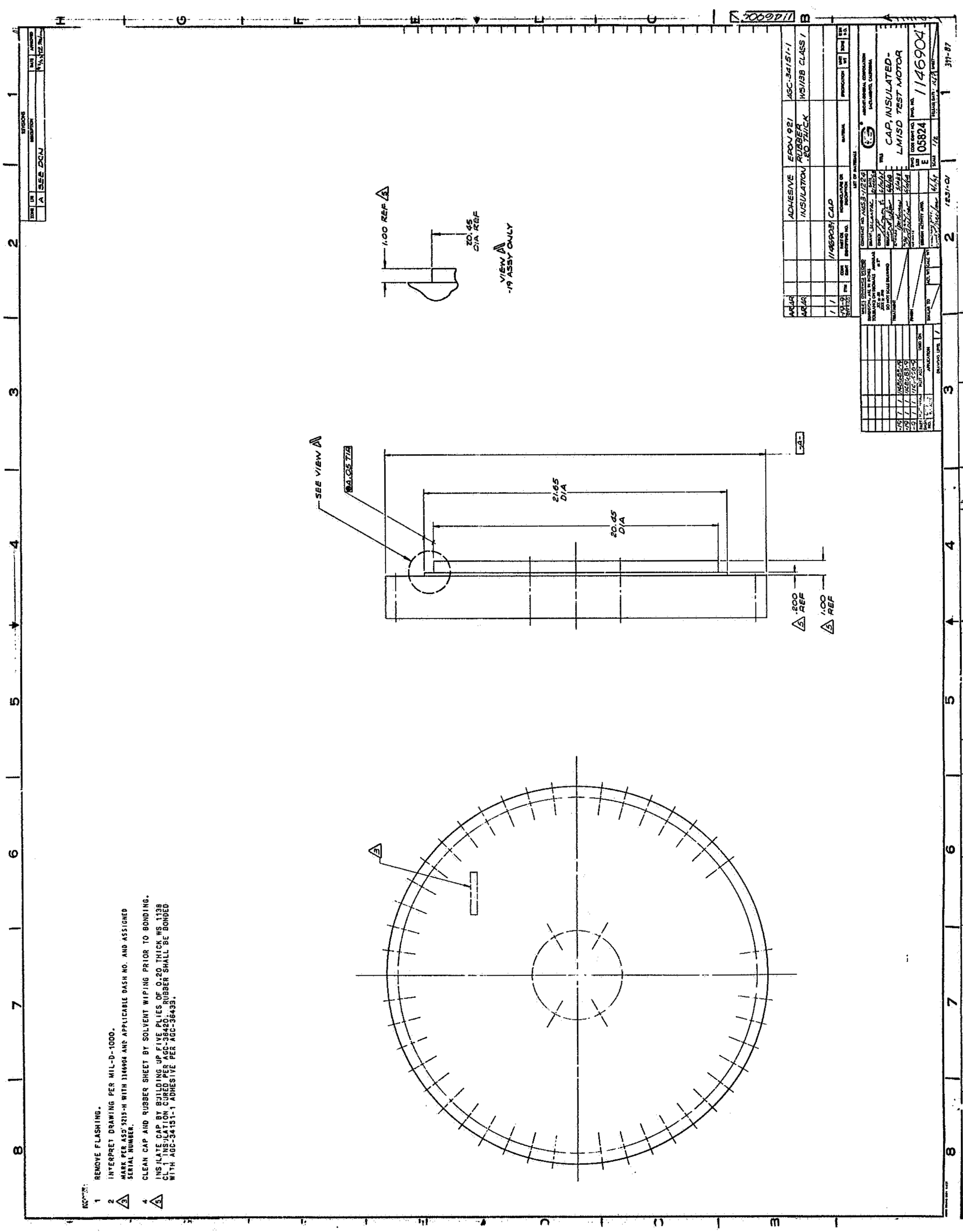

NOTES: 1 REMOVE ALL BURRS AND SHARP EDGES.
2 REMOVE ALL FLASH AND LOOSE-HANGING MATERIAL.
3 INTERPRET DRAWING PER MIL-D-1000.
4 MARK PER ASD 5215-H WITH 1146899 AND APPLICABLE DASH NUMBER.
5 BOND -1 INSERT TO 1146900-9 CLOSURE AND AGC-34151-1 ADHESIVE PER AGC-36433.
6 INSULATION SPECIMENS SHALL BE PROCESSED IN ACCORDANCE WITH AN APPROVED AGC PROCEDURE. THE MATERIALS TO BE PROCESSED WILL BE SPECIFIED BY THE PROJECT MANAGER.
7 ACCEPTABLE MATERIALS:
FM-5525, U.S. POLYMERIC, INC., CODE IDENT 27129.
MXA-5012, FIBERITE CORP, CODE IDENT 07314.
8 WRAP AND CURE FM-5525 OR MXA-5012 ASBESTOS-PHENOLIC ON -3 THROAT AS FOLLOWS:
A. APPLY BRUSH COAT OF MIL-R-9299 PHENOLIC RESIN TO INTERFACE SURFACE OF -3 THROAT.
B. WRAP ASBESTOS-PHENOLIC ON -3 THROAT TO A THICKNESS SUFFICIENT TO YIELD FINAL DIMENSIONS AFTER CURE.
C. VACUUM BAG AND CURE AT 300 TO 325 F, 100 PSIG MINIMUM AUTOCLAVE PRESSURE. CURE CYCLE DURATION TO BE TWO HOURS, MINIMUM, AT 300 TO 325 F, AS DETERMINED BY THERMOCOUPLE IN LAMINATE.
D. MACHINING TO FINAL DIMENSIONS PERMISSIBLE.
-1 DETAIL
VIEW A-A SCALE 1/8 -19 ASSY ONLY
VIEW A-A SCALE 1/8 -9 ASSY ONLY
INSULATION SPECIMEN
33° BASIC
PHENOLIC RESIN
ADHESIVE
LINER-INSERT
INSULATION SPECIMENS
CLOSURE
THROAT
INSERT
EPON 921
ATJ GRAPHITE
CLOSURE, INSULATED LMISD TEST MOTOR
05824
1146899

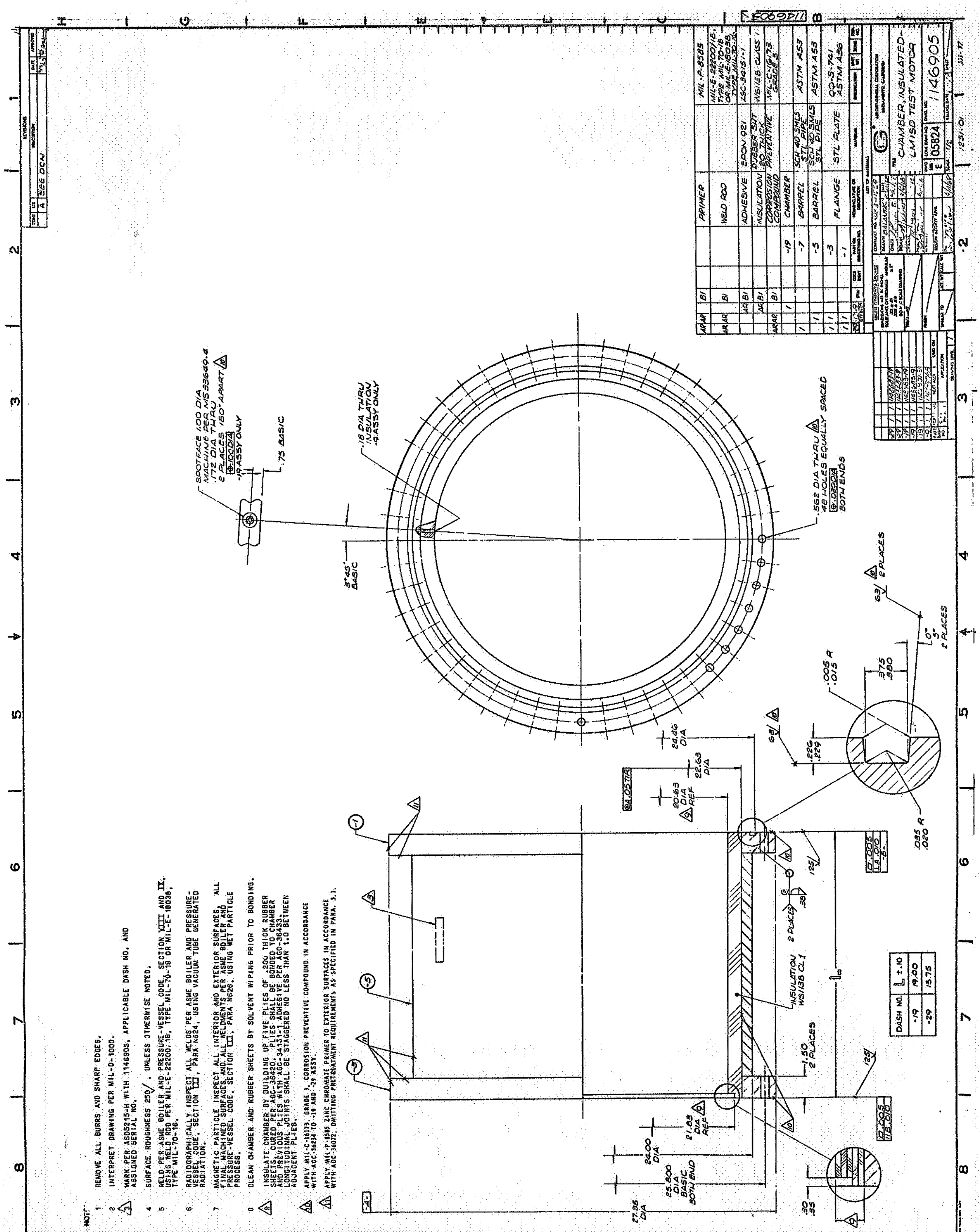

CLOSURE - LMISD TEST MOTOR
1146900
05824
PRIMER
MIL-P-8585
WELD ROD
CORROSION PREVENTIVE COMPOUND
MIL-C-16173 GRADE 3
FLANGE
STEEL
QQ-S-741
CLOSURE
.562 DIA THRU 48 HOLES EQUALLY SPACED
.290 DIA THRU 6 HOLES EQUALLY SPACED
VIEW A SCALE 1/1
VIEW B -19 ASSY ONLY
SEE VIEW A
SEE VIEW B
60° BASIC
26.00
27.35 DIA
25.800 DIA BASIC
8.000 DIA
6.800 DIA
5.220 DIA BASIC
8.60 DIA
6.650 DIA BASIC
1.746
1.750
3° BASIC
1.00 MAX
2.38 MIN
1.50
.03R
NOTES:

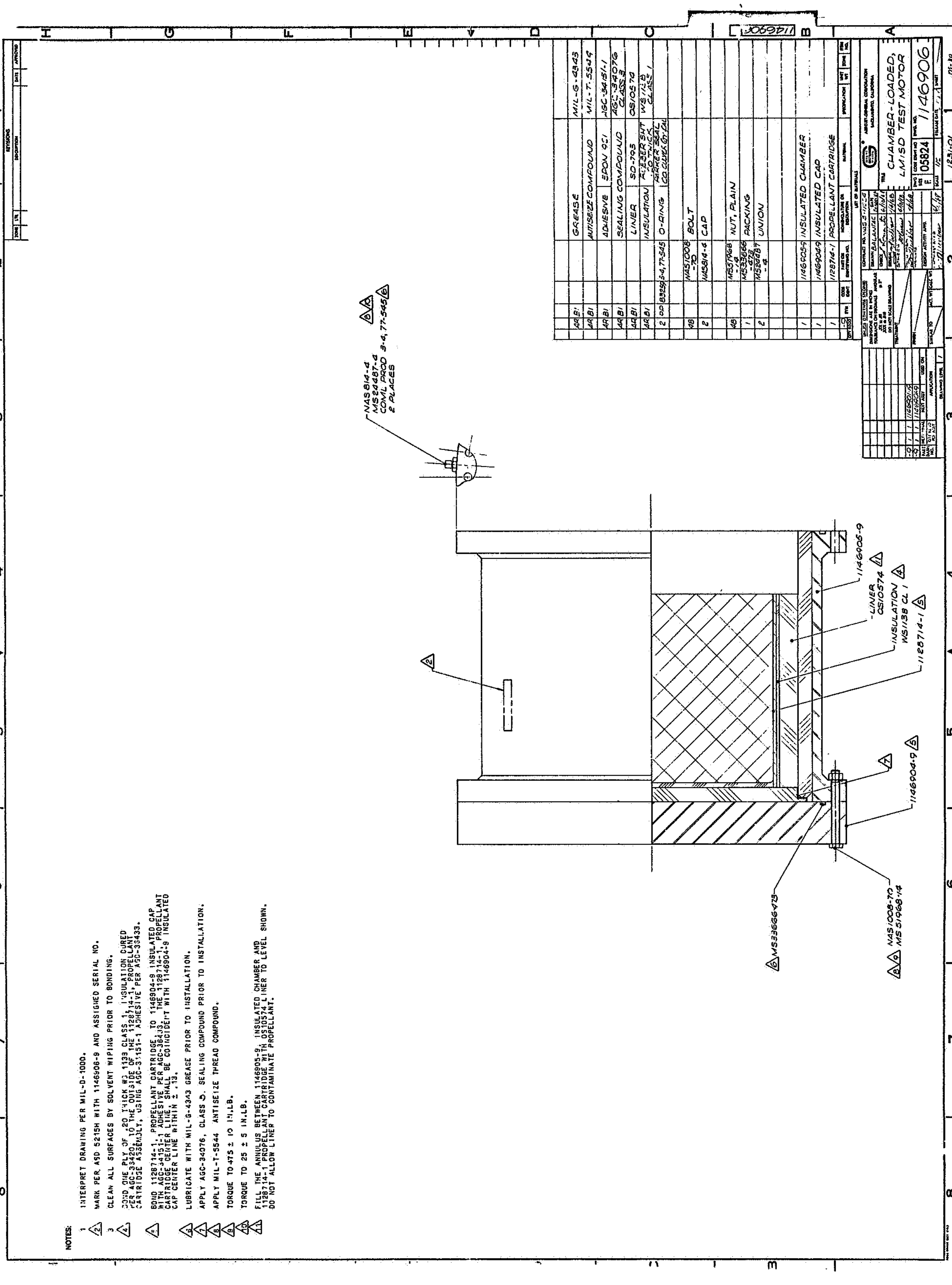

NOTES:
1 INTERPRET DRAWING PER MIL-D-1000.
2 MARK PER ASD 5215H WITH 1146901 AND APPLICABLE DASH NUMBER AND ASSIGNED SERIAL NUMBER.
3 LUBRICATE WITH MIL-G-4343 GREASE PRIOR TO INSTALLATION.
4 APPLY AGC-34076, CLASS 3, SEALING COMPOUND PRIOR TO INSTALLATION.
5 APPLY MIL-T-5544 ANTISEIZE THREAD COMPOUND.
6 TORQUE TO 475 ± 10 IN.LB.
7 THE 1143989-9, IGNITER ASSEMBLY, SHALL BE INSTALLED INTO MOTOR JUST PRIOR TO FIRING.
AUTISEIZE COMPOUND
MIL-T-5544
GREASE
MIL-G-4343
SEALING COMPOUND
AGC-34076 CLASS 3
NAS1008-44 BOLT
MS51968-14 NUT
MS33666-473 PACKING
1146069 LOADED CHAMBER
1146899-19 INSULATED CLOSURE
1146999 INSULATED CLOSURE
1143989-9 IGNITER ASSEMBLY
LIST OF MATERIALS
MOTOR ASSEMBLY
LMISD TEST MOTOR
05824
1146901
1251-01
1146899-9
1146899-19
1143989-9
NAS1008-44
MS51968-14
MS33666-473
1146006-9

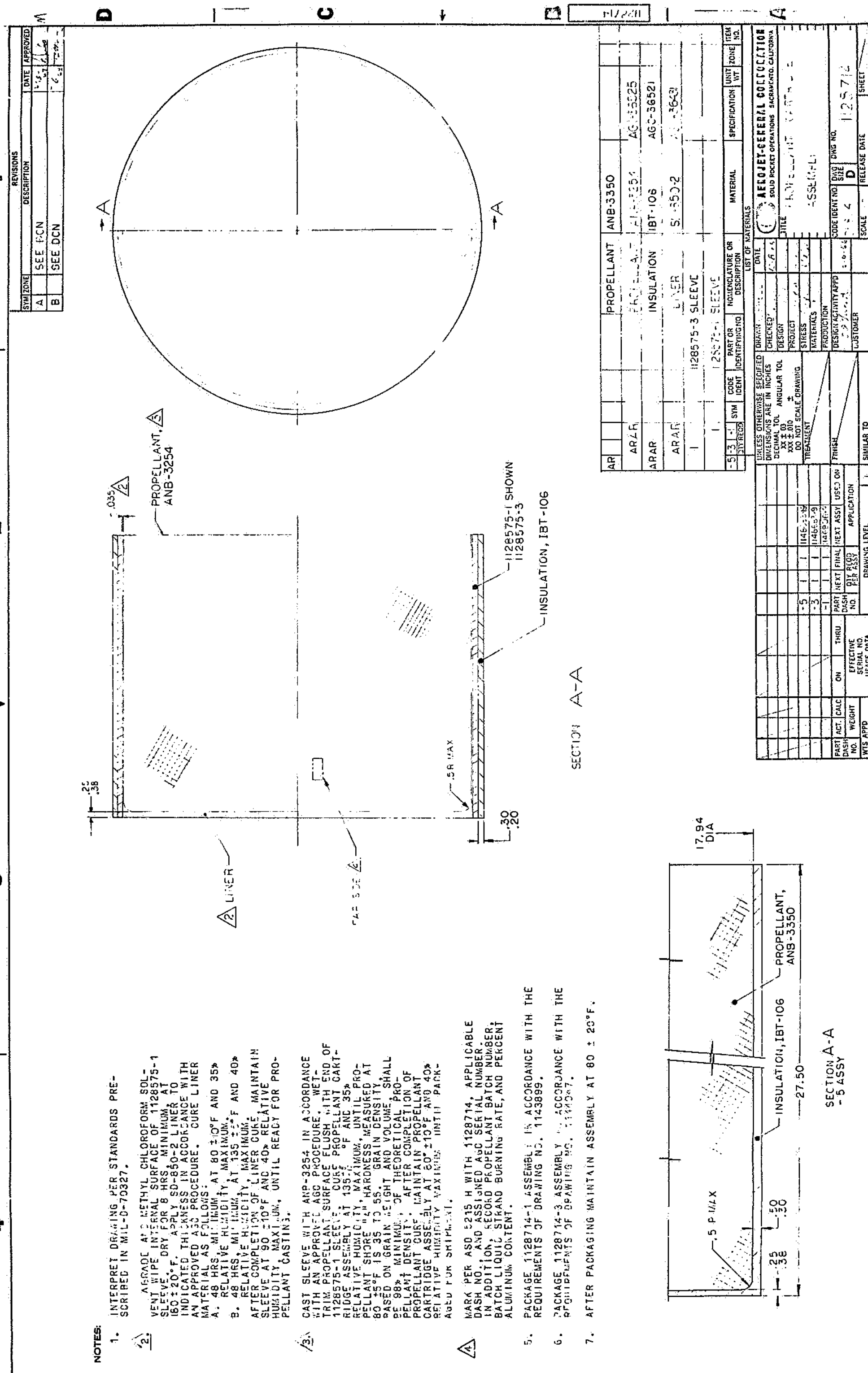

HYDROTEST CONFIGURATION
LMISD TEST MOTOR
1146902
05824
1146900-9
1146905-19
1146903-1
NAS1008-44
MS51968-14
MS33666-473
NAS1008-70
MS51968-14
MS33666-473
NAS1593-356
COML PROD.
EWB 22-8-12
-3 SEE DETAIL
-1 SEE DETAIL
-1 DETAIL
-3 DETAIL
VIEW A
SCALE 2/1
.331 DIA THRU
6.70
DIA
.250
5.441
5.431
DIA
5.365
5.355
DIA
5.885
5.875
DIA
1.500
1.120
BREAK CORNER
APPROX .005R
2 PLACES
MIL-G-4343
GREASE
BOLT
PACKING
NUT
CHAMBER
CAP
CLOSURE
RETAINER
PLUG
STEEL
QQ-S-74:
NOTES:
REMOVE ALL BURRS AND SHARP EDGES.


NOTE
1 REMOVE ALL BURRS AND SHARP EDGES.
2 INTERPRET DRAWING PER MIL-D-1000.
3 MARK PER ASD 5215H WITH 1146903-1 AND ASSIGNED SERIAL NUMBER.
4 SURFACE ROUGHNESS 250 , UNLESS OTHERWISE NOTED.
5 APPLY MIL-C-16173 GRADE 3, CORROSION PREVENTIVE PER AGC 36234.
6.500 DIA BASIC
.500-20UNF-2B X .78 DEEP
6 HOLES EQUALLY SPACED
.562 DIA THRU
48 HOLES EQUALLY SPACED
25.800 DIA BASIC
27.35 DIA
24.46 DIA
.300
.005 R
.015 R
.375
.380
.226
.229
.035 R
.020 R
0°
5°
2 PLACES
CORROSION PREVENTIVE
MIL-C-16173 GRADE 3
STEEL, CARBON (ASTM A-36)
QQ-S-741
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA
CAP-
LMISD TEST MOTOR
05824
1146903


NOTES:
1 REMOVE FLASHING.
2 INTERPRET DRAWING PER MIL-D-1000.
3 MARK PER AS 5215-H WITH 1146904 AND APPLICABLE DASH NO. AND ASSIGNED SERIAL NUMBER.
4 CLEAN CAP AND RUBBER SHEET BY SOLVENT WIPING PRIOR TO BONDING.
5 INSULATE CAP BY BUILDING UP FIVE PLIES OF 0.20 THICK WS 1138 CL. 1 INSULATION CURED PER AGC-36420. RUBBER SHALL BE BONDED WITH AGC-34151-1 ADHESIVE PER AGC-36439.
SEE VIEW A
21.65 DIA
20.45 DIA
.200 REF
1.00 REF
1.00 REF
20.45 DIA REF
VIEW A -19 ASSY ONLY
ADHESIVE
EPON 921
AGC-34151-1
INSULATION
RUBBER .20 THICK
WS1138 CLASS I
1146903 CAP
CAP, INSULATED-LMISD TEST MOTOR
03824
1146904


CHAMBER, INSULATED-LM150 TEST MOTOR
1146905


NOTES:
1 INTERPRET DRAWING PER MIL-D-1000.
2 MARK PER ASD 5215H WITH 1146906-9 AND ASSIGNED SERIAL NO.
3 CLEAN ALL SURFACES BY SOLVENT WIPING PRIOR TO BONDING.
4 BOND ONE PLY OF .20 THICK WS 1138 CLASS 1, INSULATION CURED PER AGC-33420, TO THE OUTSIDE OF THE 1128714-1, PROPELLANT CARTRIDGE ASSEMBLY, USING AGC-31151-1 ADHESIVE PER AGC-36433.
5 BOND 1128714-1, PROPELLANT CARTRIDGE, TO 1146904-9 INSULATED CAP WITH AGC-34151-1 ADHESIVE PER AGC-36433. THE 1128714-1, PROPELLANT CARTRIDGE CENTER LINE, SHALL BE COINCIDENT WITH 1146904-9 INSULATED CAP CENTER LINE WITHIN ± .13.
6 LUBRICATE WITH MIL-G-4343 GREASE PRIOR TO INSTALLATION.
7 APPLY AGC-34076, CLASS 5, SEALING COMPOUND PRIOR TO INSTALLATION.
8 APPLY MIL-T-5544 ANTISEIZE THREAD COMPOUND.
9 TORQUE TO 475 ± 10 IN.LB.
10 TORQUE TO 25 ± 5 IN.LB.
11 FILL THE ANNULUS BETWEEN 1146905-9, INSULATED CHAMBER AND 1128714-1 PROPELLANT CARTRIDGE WITH OS10574 LINER TO LEVEL SHOWN. DO NOT ALLOW LINER TO CONTAMINATE PROPELLANT.
NAS814-4
MS28487-4
COML PROD 3-4, 77-545
2 PLACES
1146905-9
LINER OS10574
INSULATION WS1138 CL 1
1128714-1
1146904-9
MS33666-473
NAS1008-70
MS51968-14
GREASE MIL-G-4343
ANTISEIZE COMPOUND MIL-T-5544
ADHESIVE EPON 9C1 AGC-34151-1
SEALING COMPOUND AGC-34076 CLASS 5
LINER SD-795 OS10574
INSULATION RUBBER SHT .20 THICK WS1138 CLASS 1
O-RING
NAS1008-70 BOLT
NAS814-4 CAP
MS51968 NUT, PLAIN
MS33666-473 PACKING
MS28487-4 UNION
1146905-9 INSULATED CHAMBER
1146904-9 INSULATED CAP
1128714-1 PROPELLANT CARTRIDGE
AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA
CHAMBER-LOADED, LMSD TEST MOTOR
05824
1146906


NOTES:
1. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327.
7. AFTER PACKAGING MAINTAIN ASSEMBLY AT 80 ± 20°F.
PROPELLANT, ANB-3254
LINER
INSULATION, IBT-106
1128575-1 SHOWN
1128575-3
SECTION A-A
PROPELLANT, ANB-3350
SECTION A-A
-5 ASSY
17.94 DIA
27.50
REVISIONS
SEE DCN
PROPELLANT
ANB-3350
INSULATION
IBT-106
1128575-3 SLEEVE
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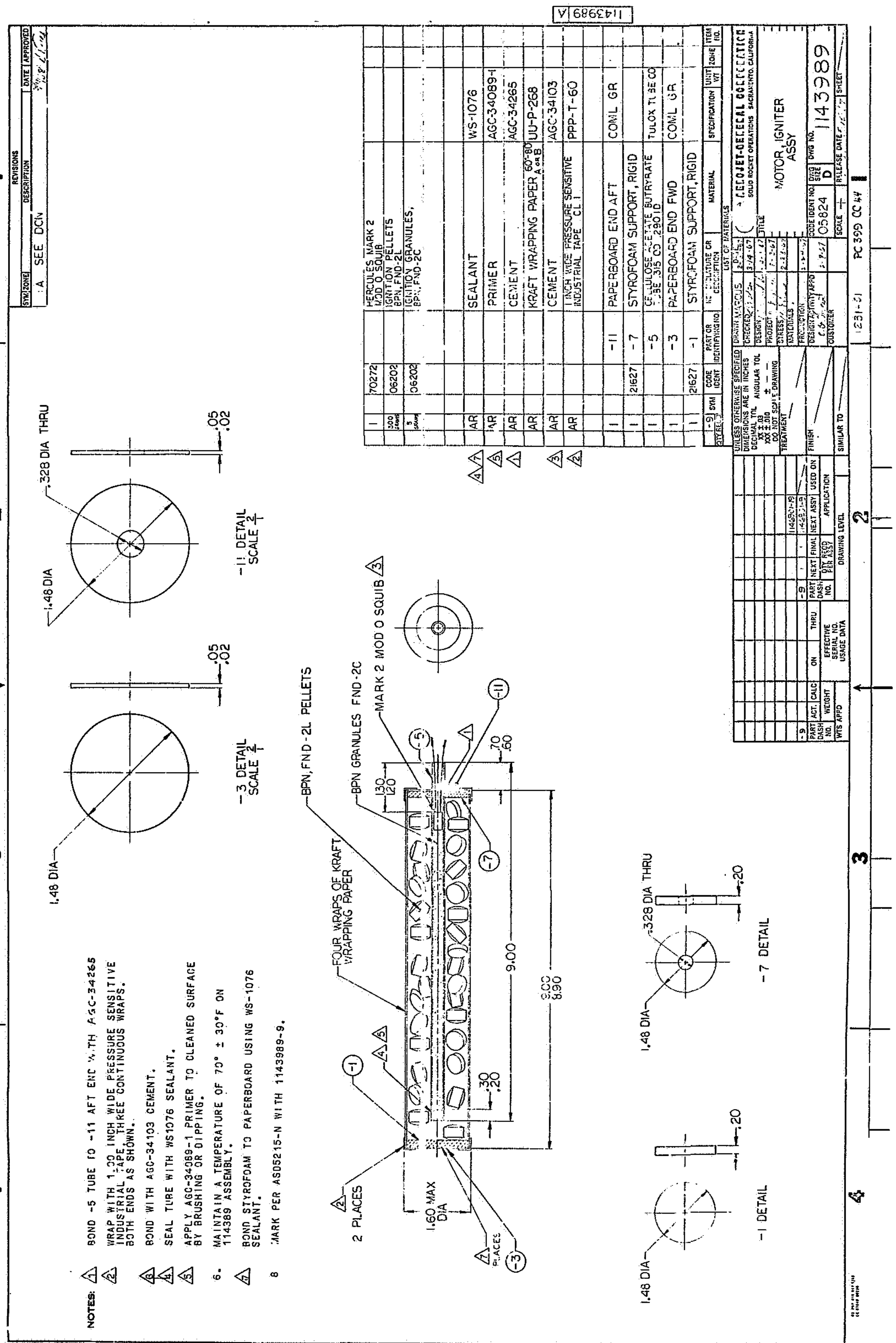
SOLID ROCKET OPERATIONS SACRAMENTO, CALIFORNIA


1143989 A
NOTES:
BOND -5 TUBE TO -11 AFT END WITH AGC-34265
WRAP WITH 1.00 INCH WIDE PRESSURE SENSITIVE INDUSTRIAL TAPE, THREE CONTINUOUS WRAPS. BOTH ENDS AS SHOWN.
BOND WITH AGC-34103 CEMENT.
SEAL TUBE WITH WS1076 SEALANT.
APPLY AGC-34089-1 PRIMER TO CLEANED SURFACE BY BRUSHING OR DIPPING.
6. MAINTAIN A TEMPERATURE OF 70° ± 30°F ON 114389 ASSEMBLY.
BOND STYROFOAM TO PAPERBOARD USING WS-1076 SEALANT.
8 MARK PER ASD5215-N WITH 1143989-9.
FOUR WRAPS OF KRAFT WRAPPING PAPER
BPN, FND-2L PELLETS
BPN GRANULES FND-2C
MARK 2 MOD 0 SQUIB
2 PLACES
1.60 MAX DIA
9.00
-1 DETAIL
-3 DETAIL SCALE 2
-11 DETAIL SCALE 2
-7 DETAIL
1.48 DIA
.328 DIA THRU
HERCULES MARK 2 MOD 0 SQUIB
IGNITION PELLETS BPN, FND-2L
IGNITION GRANULES, BPN, FND-2C
SEALANT
PRIMER
CEMENT
KRAFT WRAPPING PAPER
CEMENT
1 INCH WIDE PRESSURE SENSITIVE INDUSTRIAL TAPE CL 1
PAPERBOARD END AFT
STYROFOAM SUPPORT, RIGID
CELLULOSE ACETATE BUTYRATE
PAPERBOARD END FWD
STYROFOAM SUPPORT, RIGID
WS-1076
AGC-34089-1
AGC-34265
UU-P-268
AGC-34103
PPP-T-60
COML GR
COML GR
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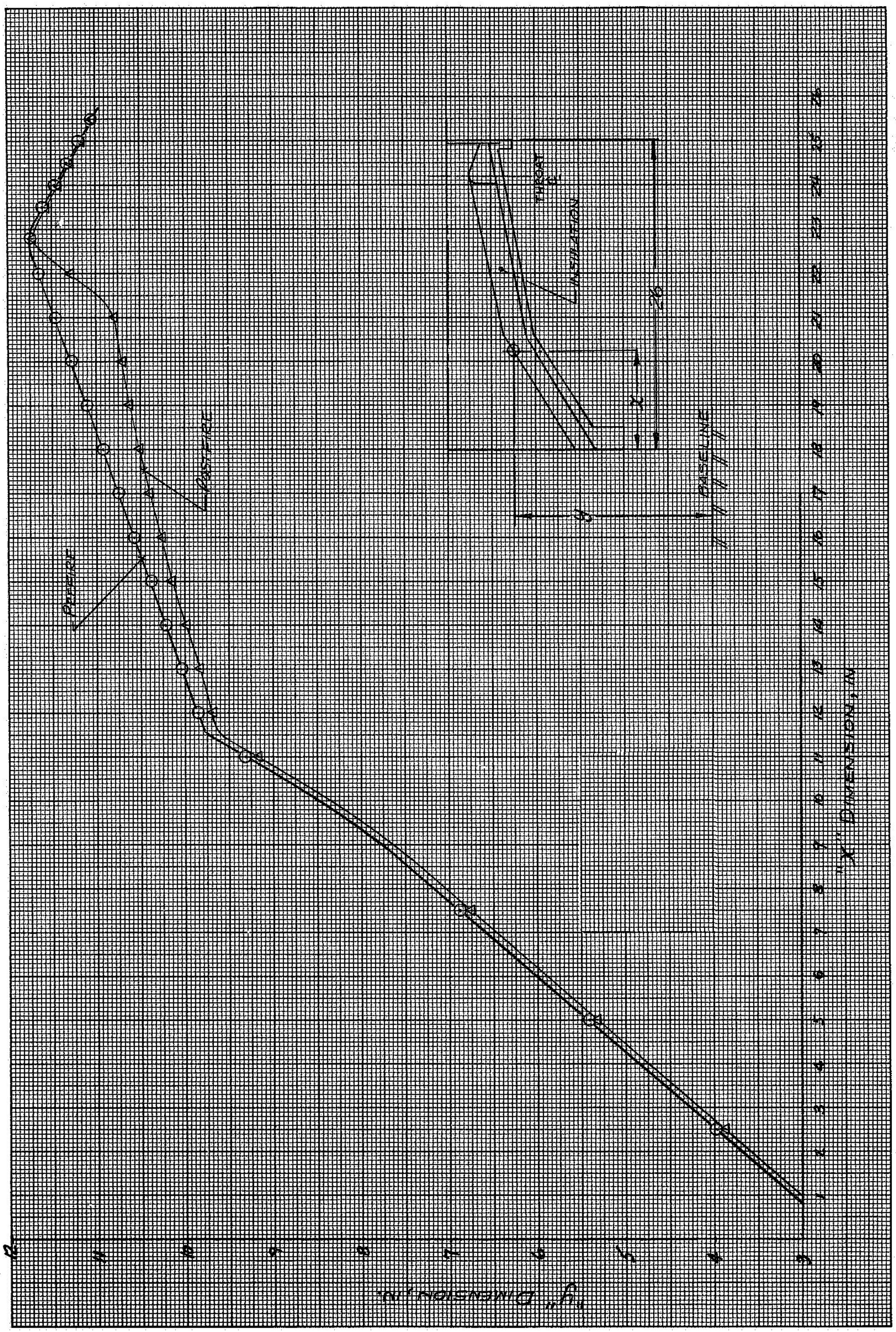
1143989

APPENDIX III

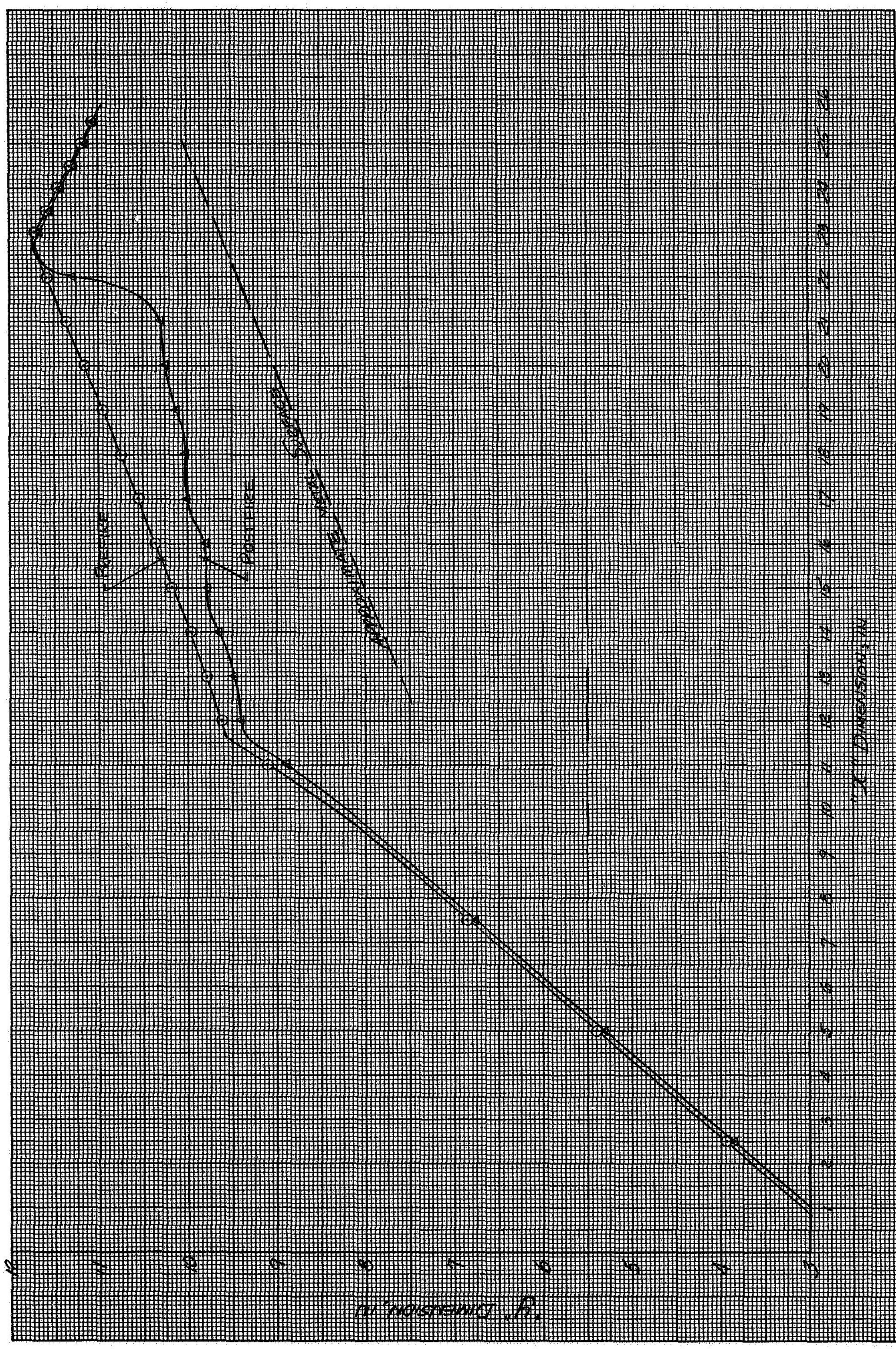
INDIVIDUAL INSULATION MATERIAL SPECIMEN PRE- AND POSTTEST PROFILES FOR MOTORS S/N I-1, I-2, AND I-3A

FIGURE LIST



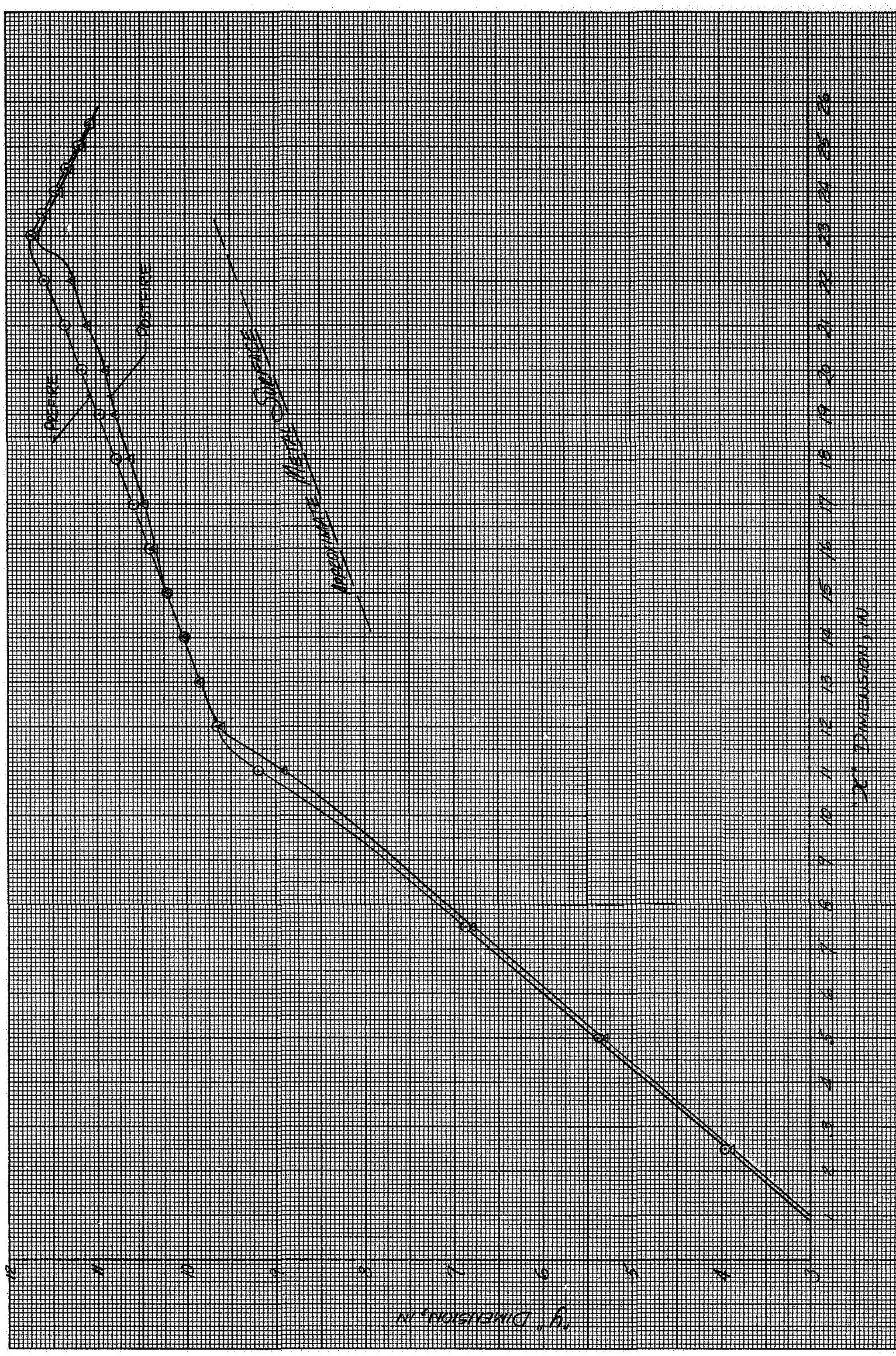
Motor S/N I-1, 0° - V-44 Specimen Profile

Figure 1



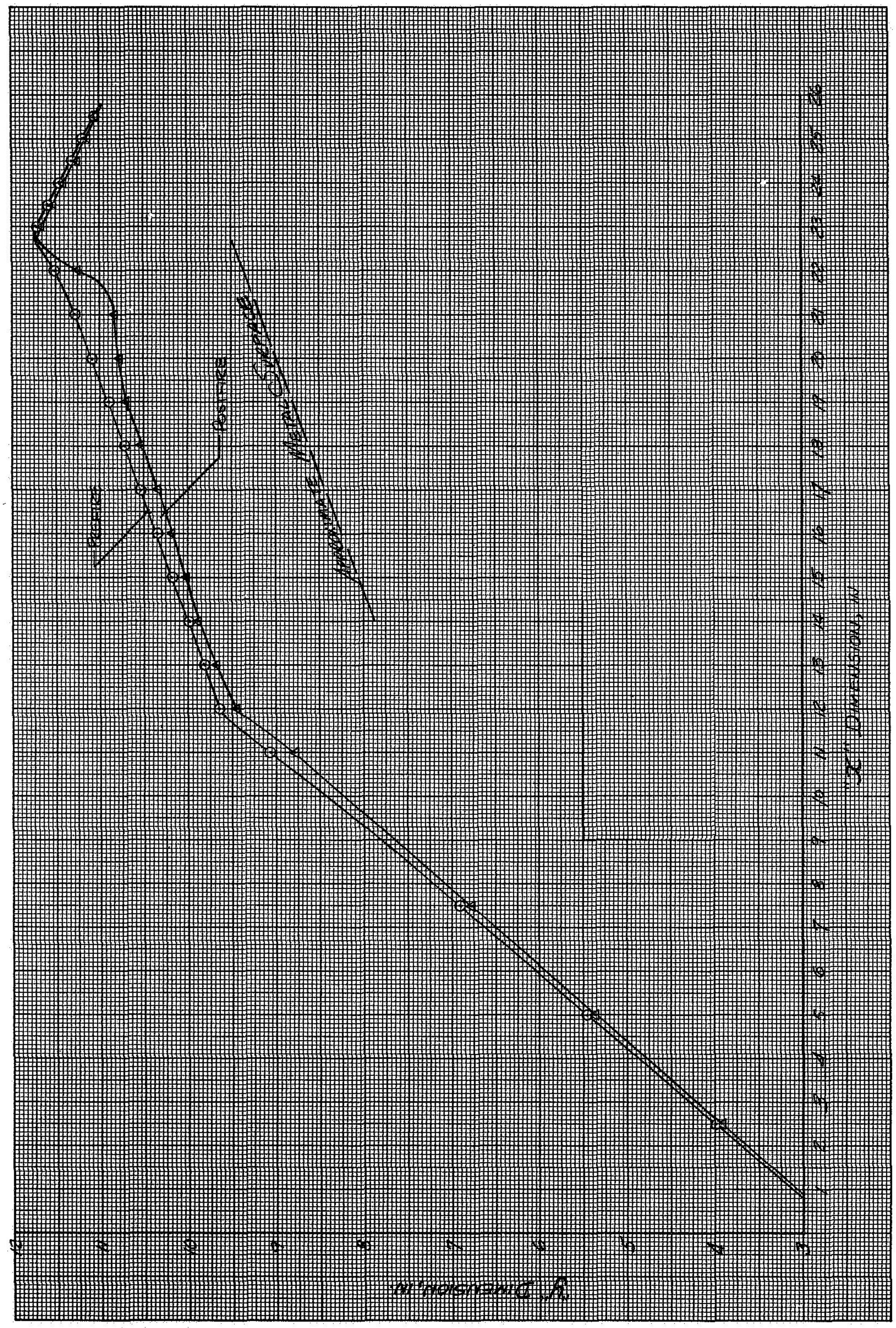
Motor S/N I-1, 45° - IBS-108 Specimen Profile

Figure 2



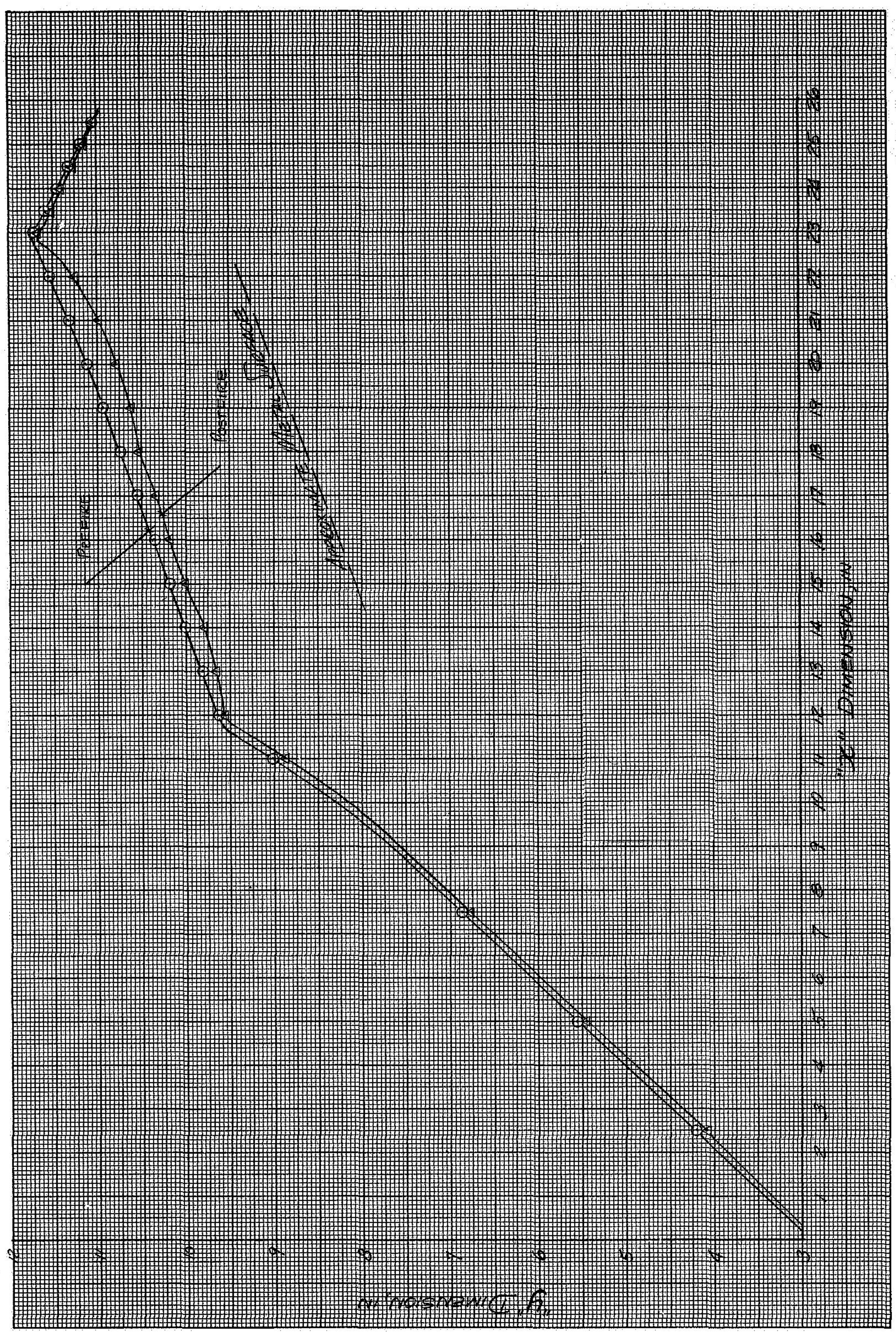
Motor S/N I-1, 90° - V-61 Specimen Profile

Figure 3



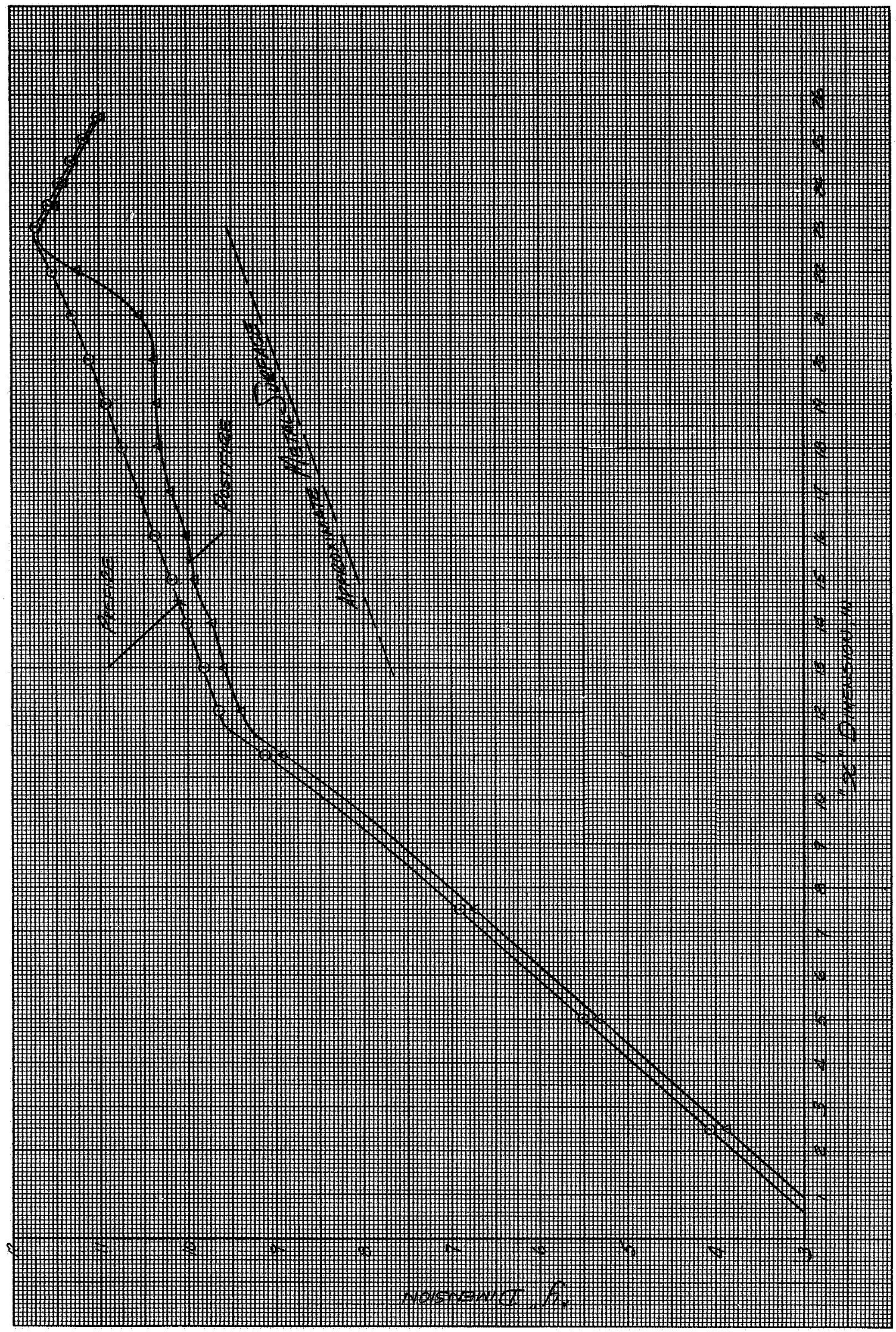
Motor S/N I-1, 135° - IBS-107 Specimen Profile

Figure 4



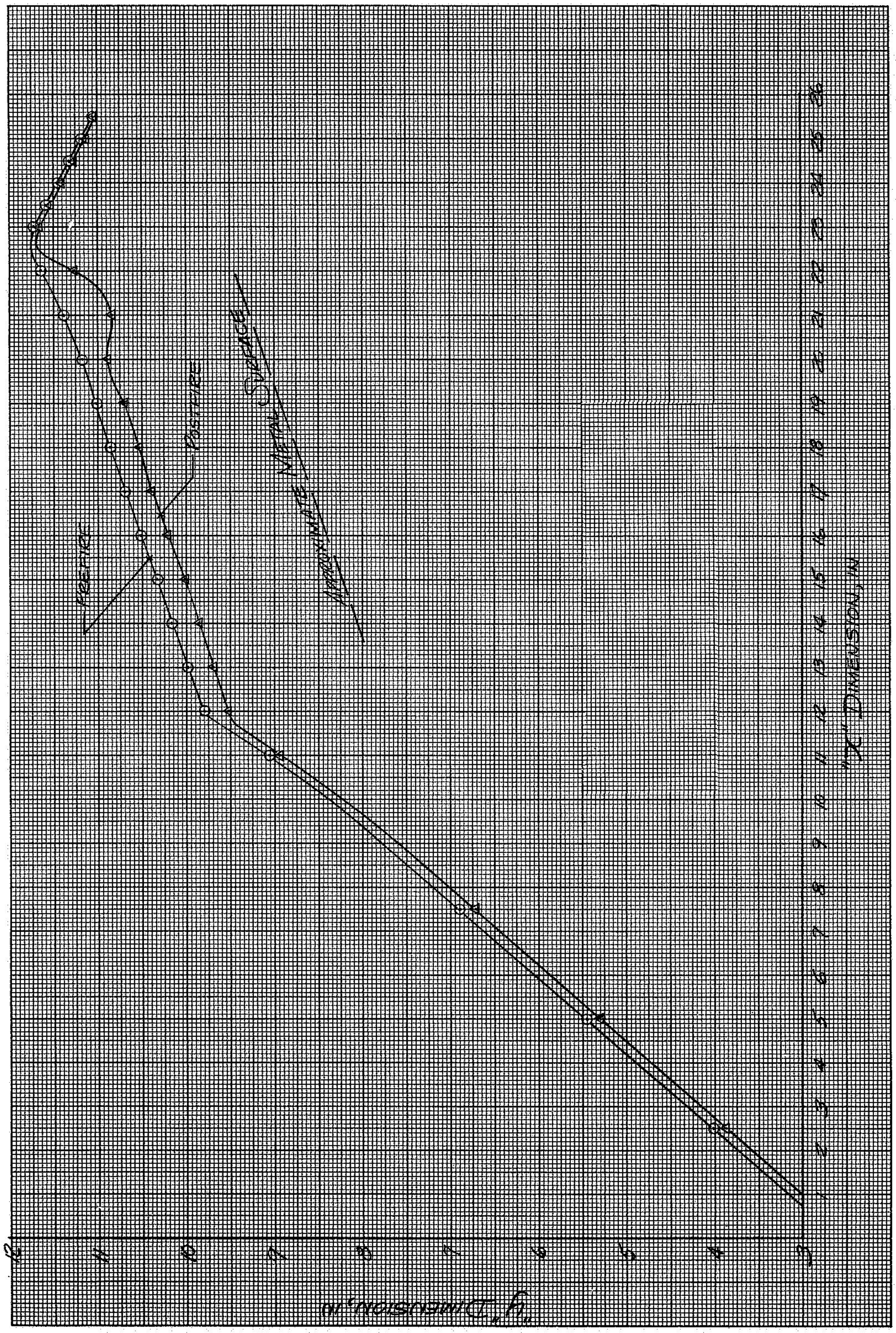
Motor S/N I-1, 180° - IBT-100 Specimen Profile

Figure 5



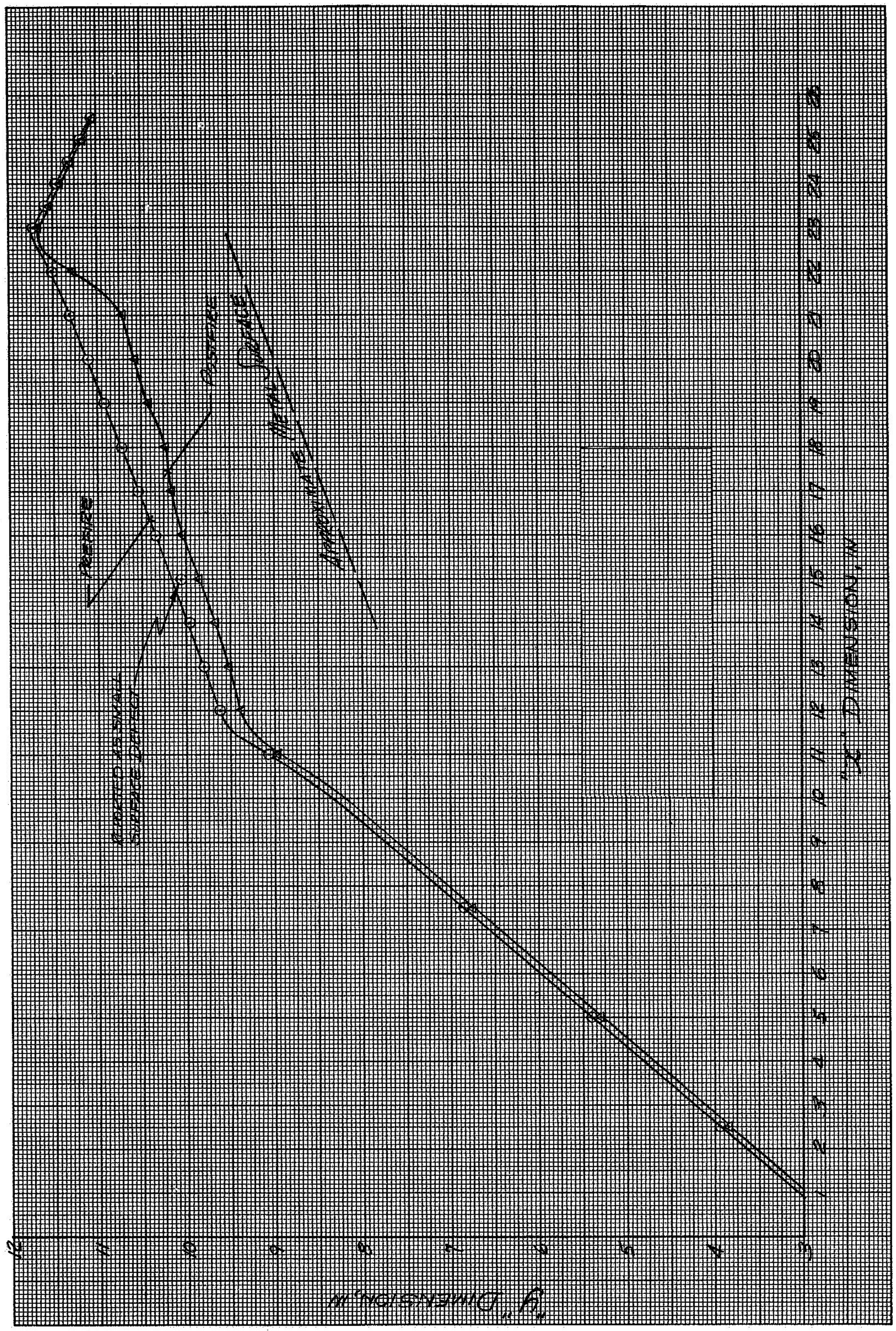
Motor S/N I-1, 225° - IBC-101 Specimen Profile

Figure 6



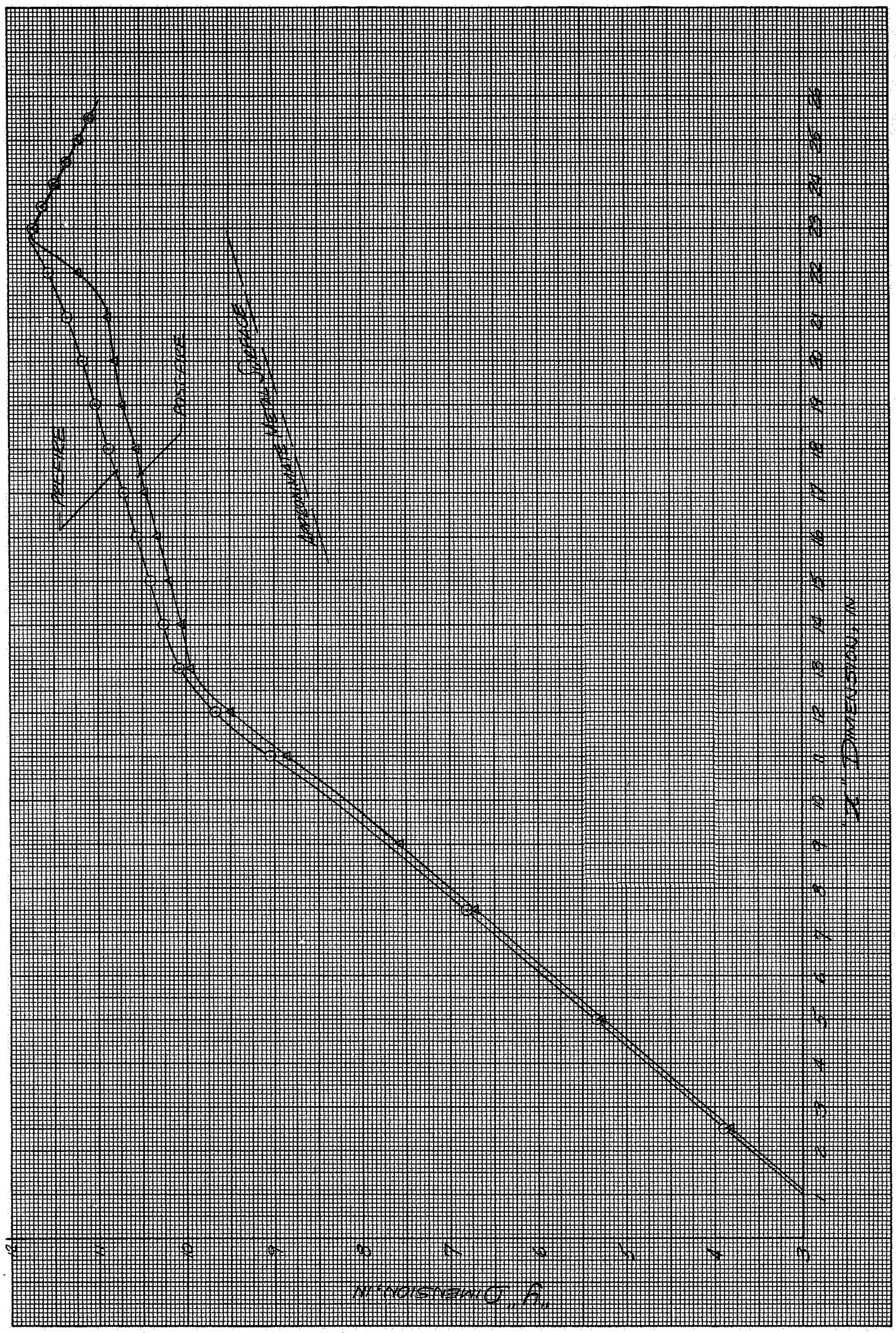
Motor S/N I-1, 270° - IBT-106 Specimen Profile

Figure 7



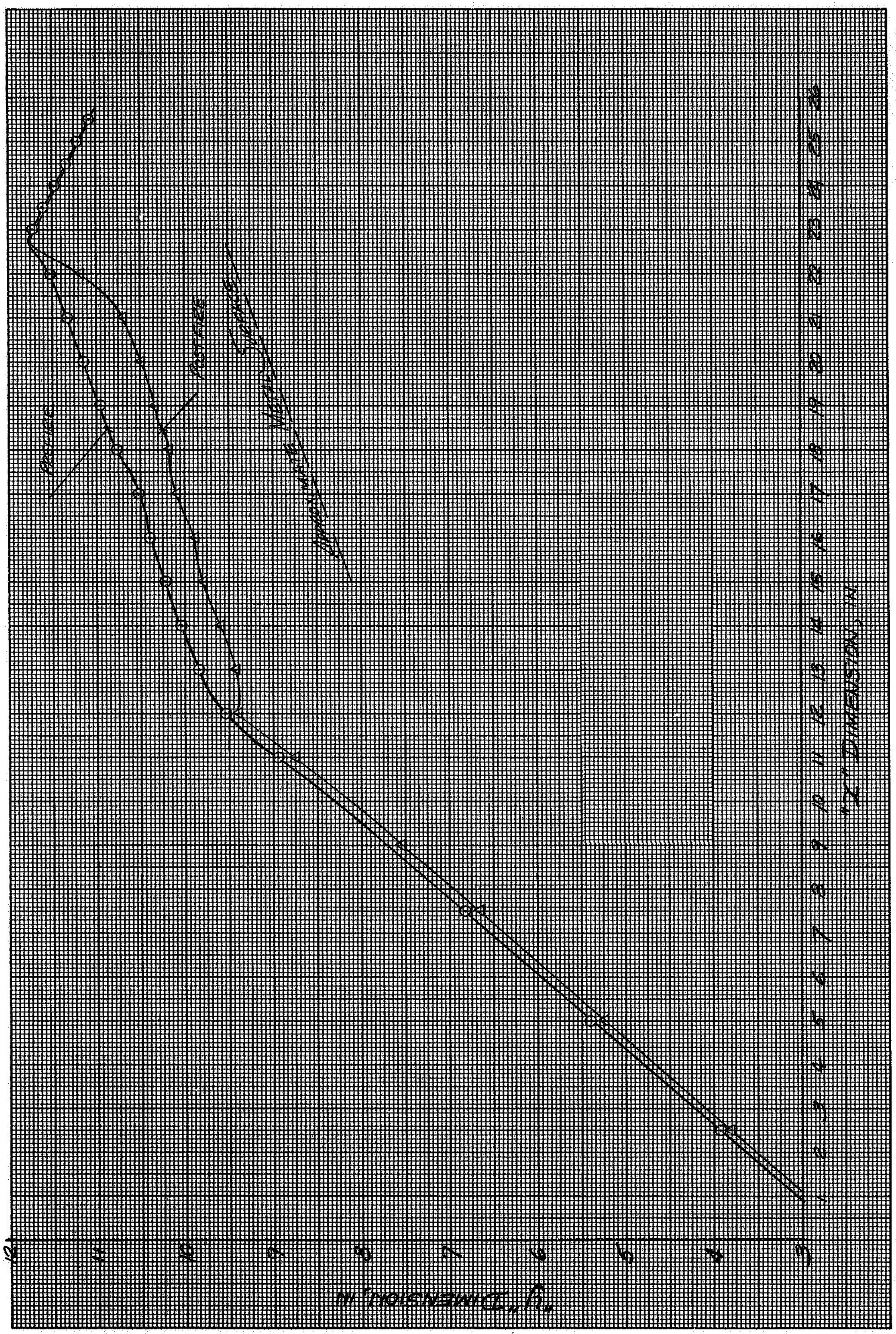
Motor S/N I-1, 315 ° - IBS-109 Specimen Profile

Figure 8



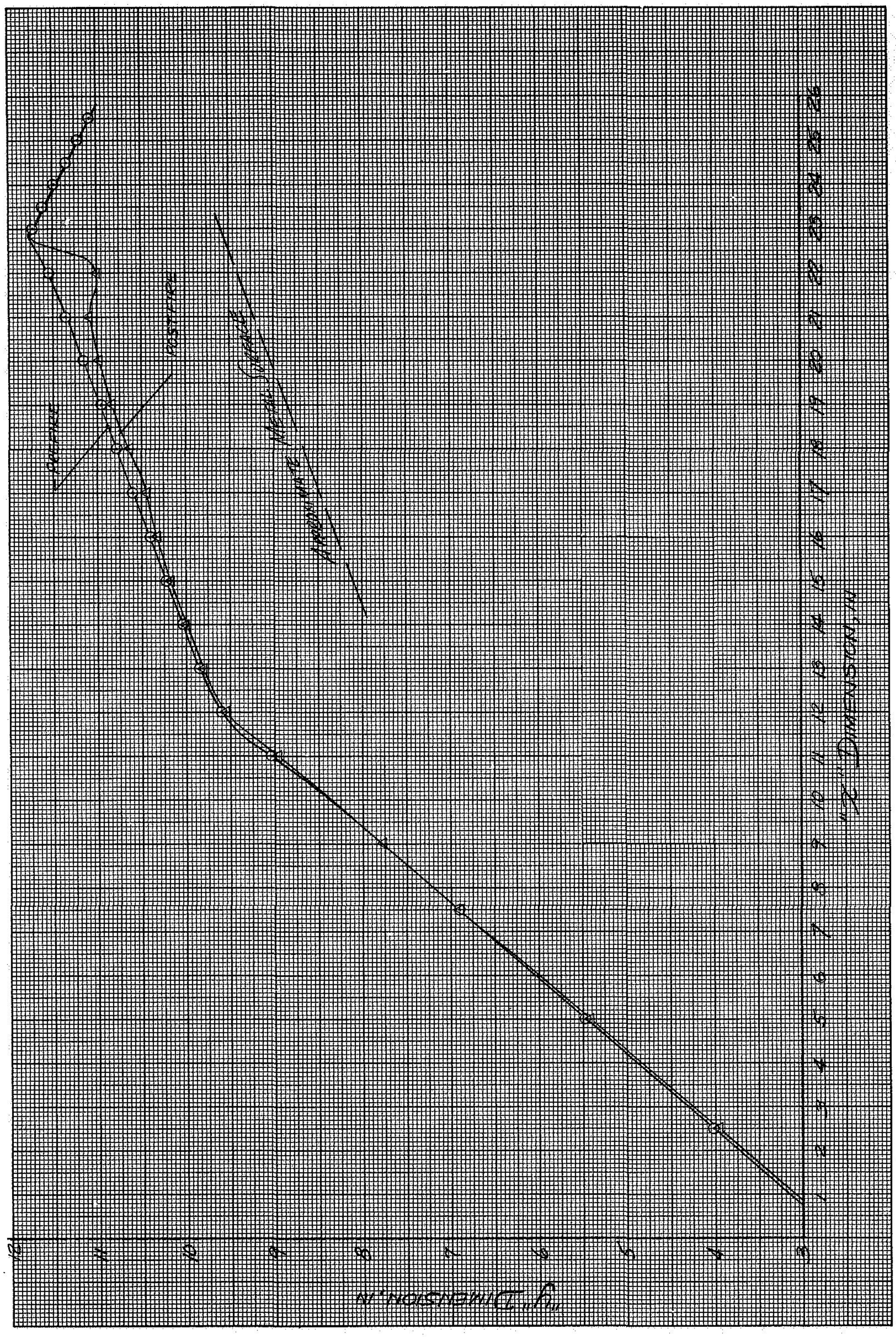
Motor S/N I-2, 0° - V-44 Specimen Profile

Figure 9



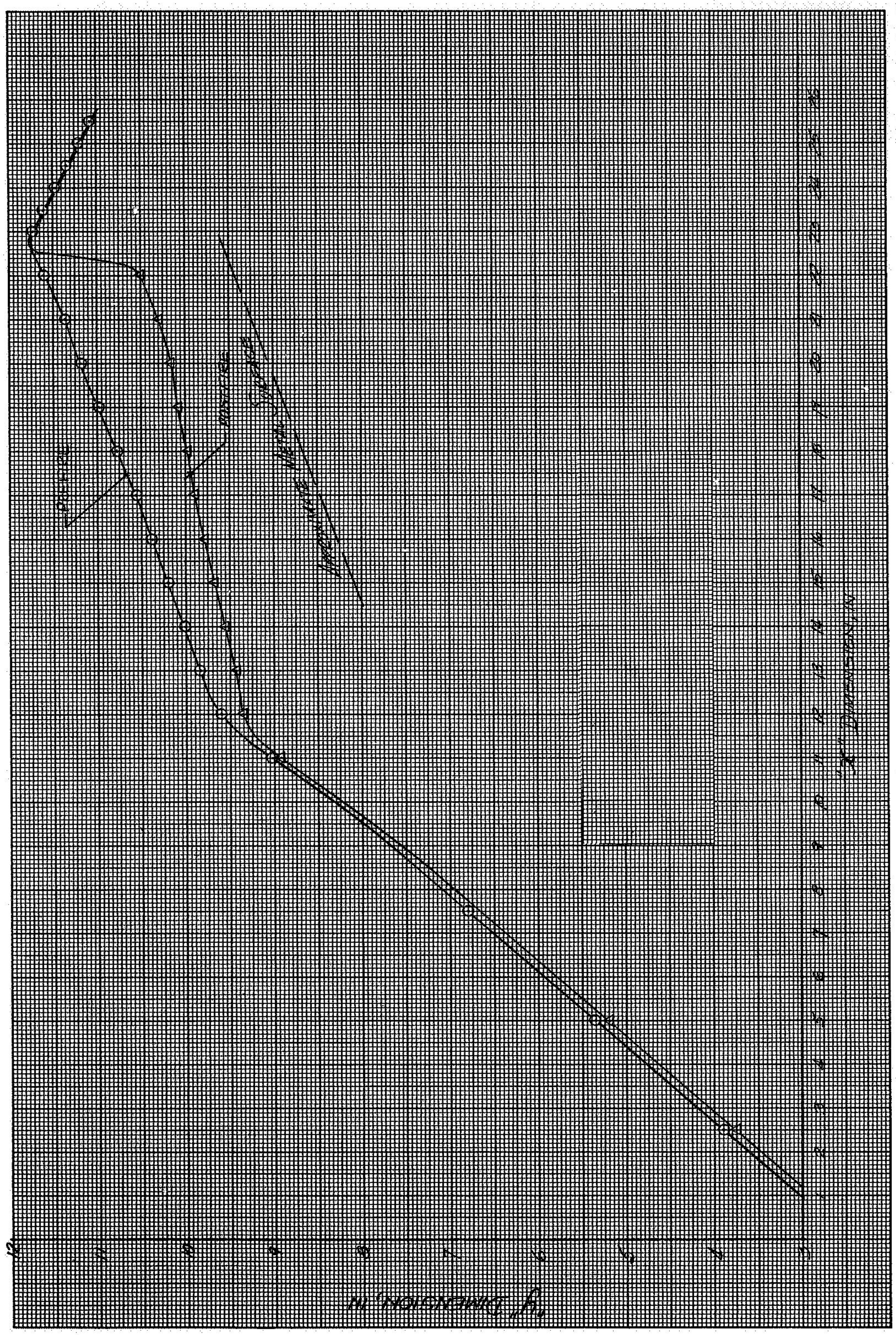
Motor S/N I-2, 45° - 40SD-80 Specimen Profile

Figure 10



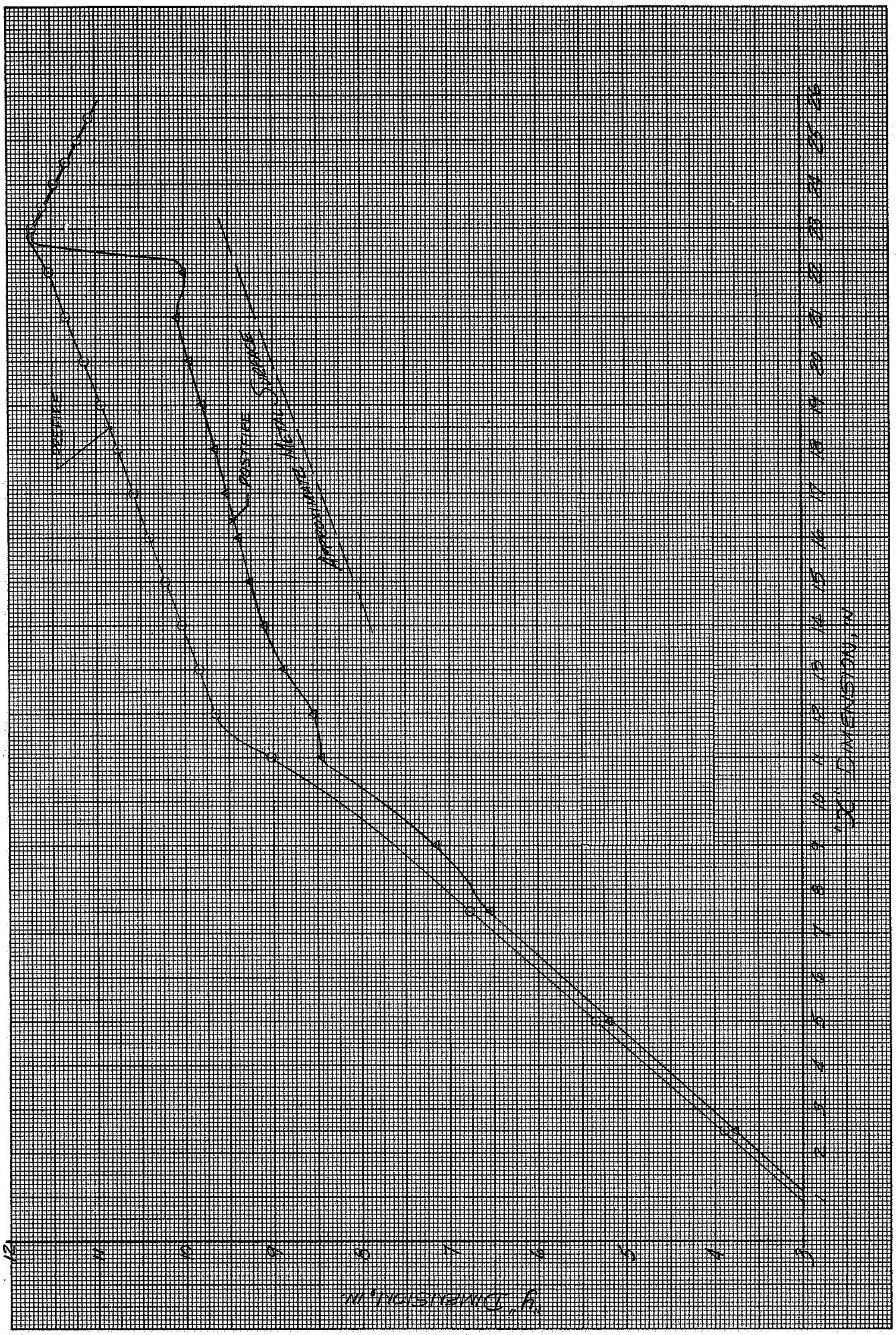
Motor S/N I-2, 90° - V-61 Specimen Profile

Figure 11



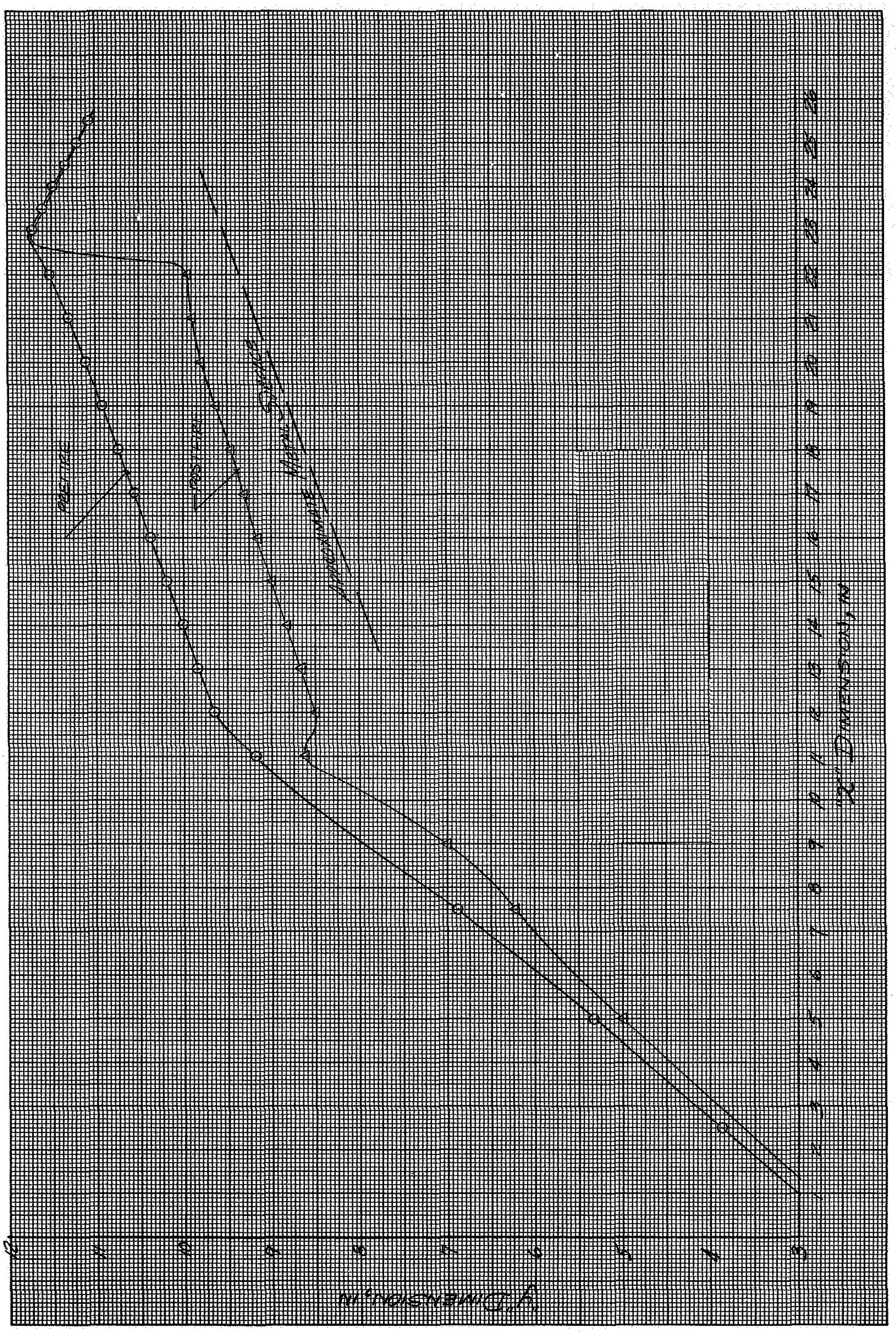
Motor S/N I-2, 135° - Avcoat III Specimen Profile

Figure 12



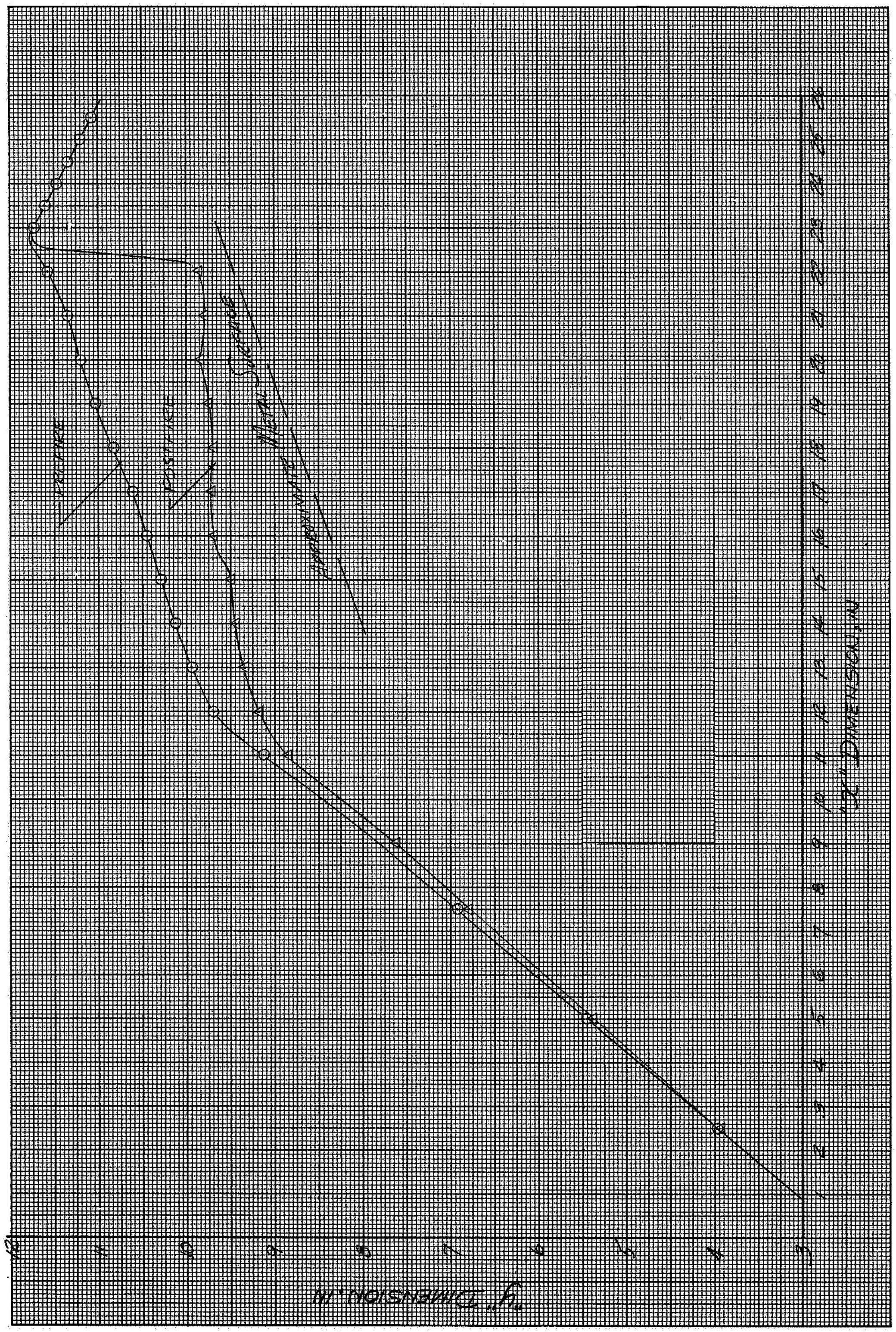
Motor S/N I-2, 180° - RTV-511 Specimen Profile

Figure 13



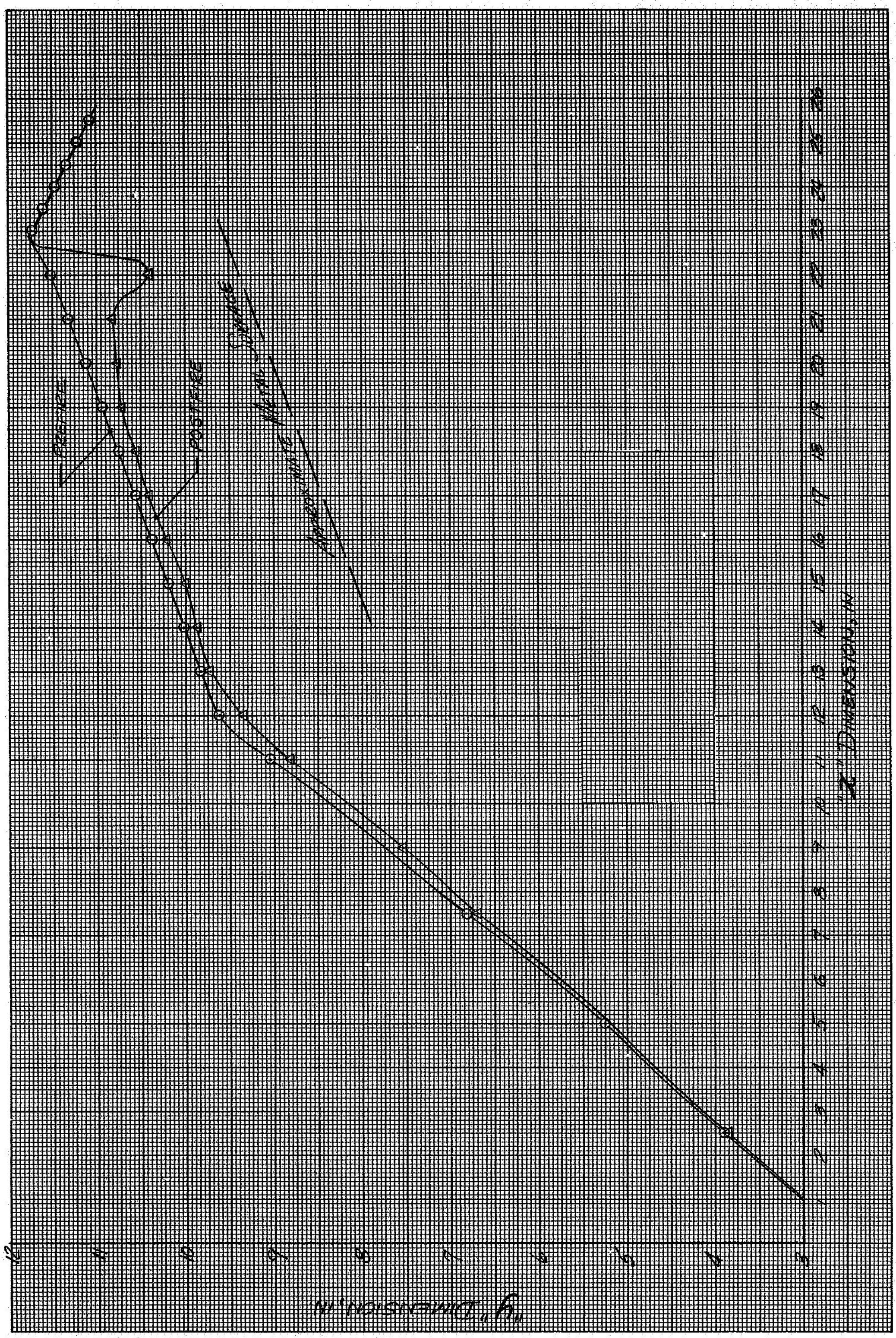
Motor S/N I-2, 225° - PR1933-2 Specimen Profile

Figure 14



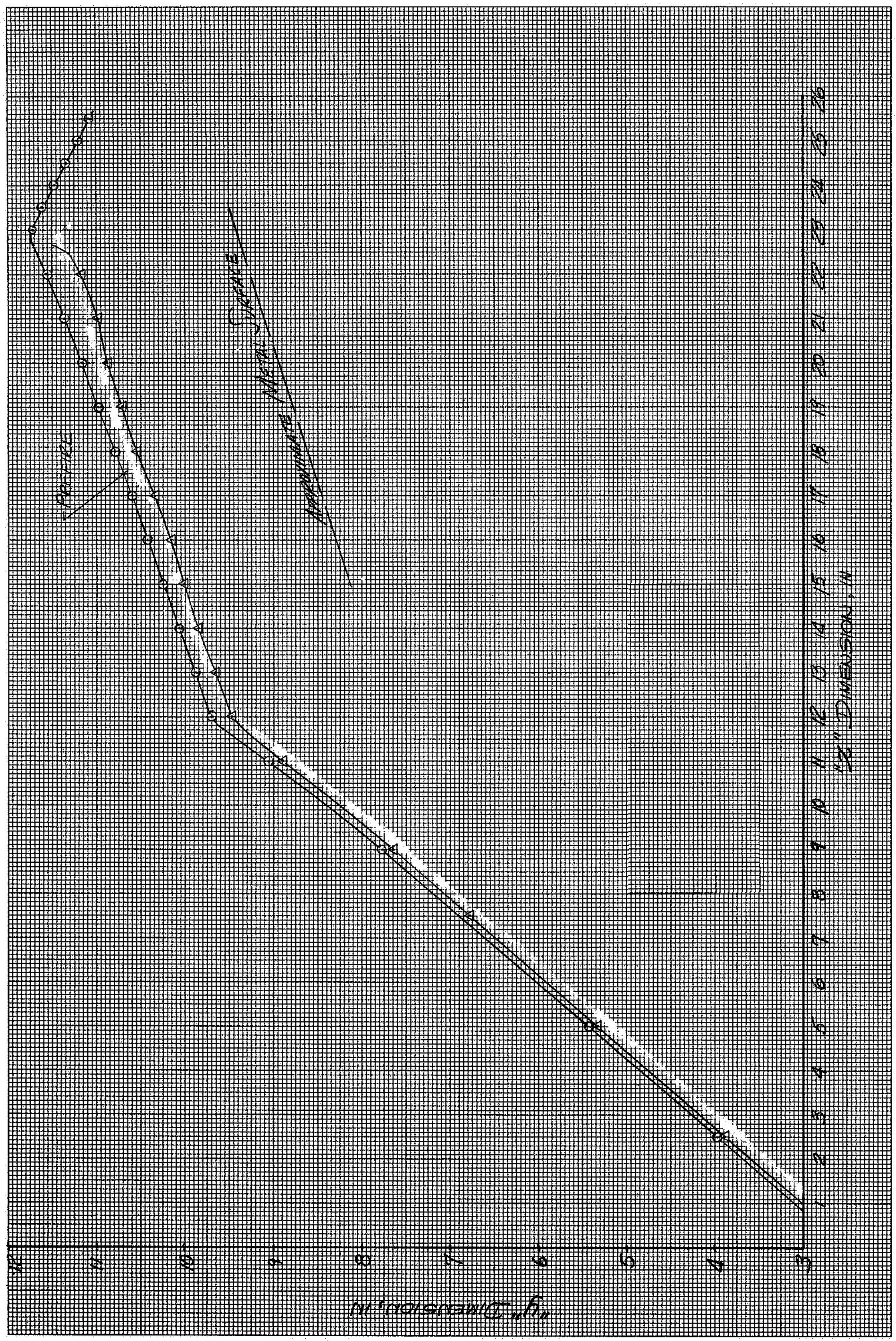
Motor S/N I-2, 270° - TBS-758 Specimen Profile

Figure 15



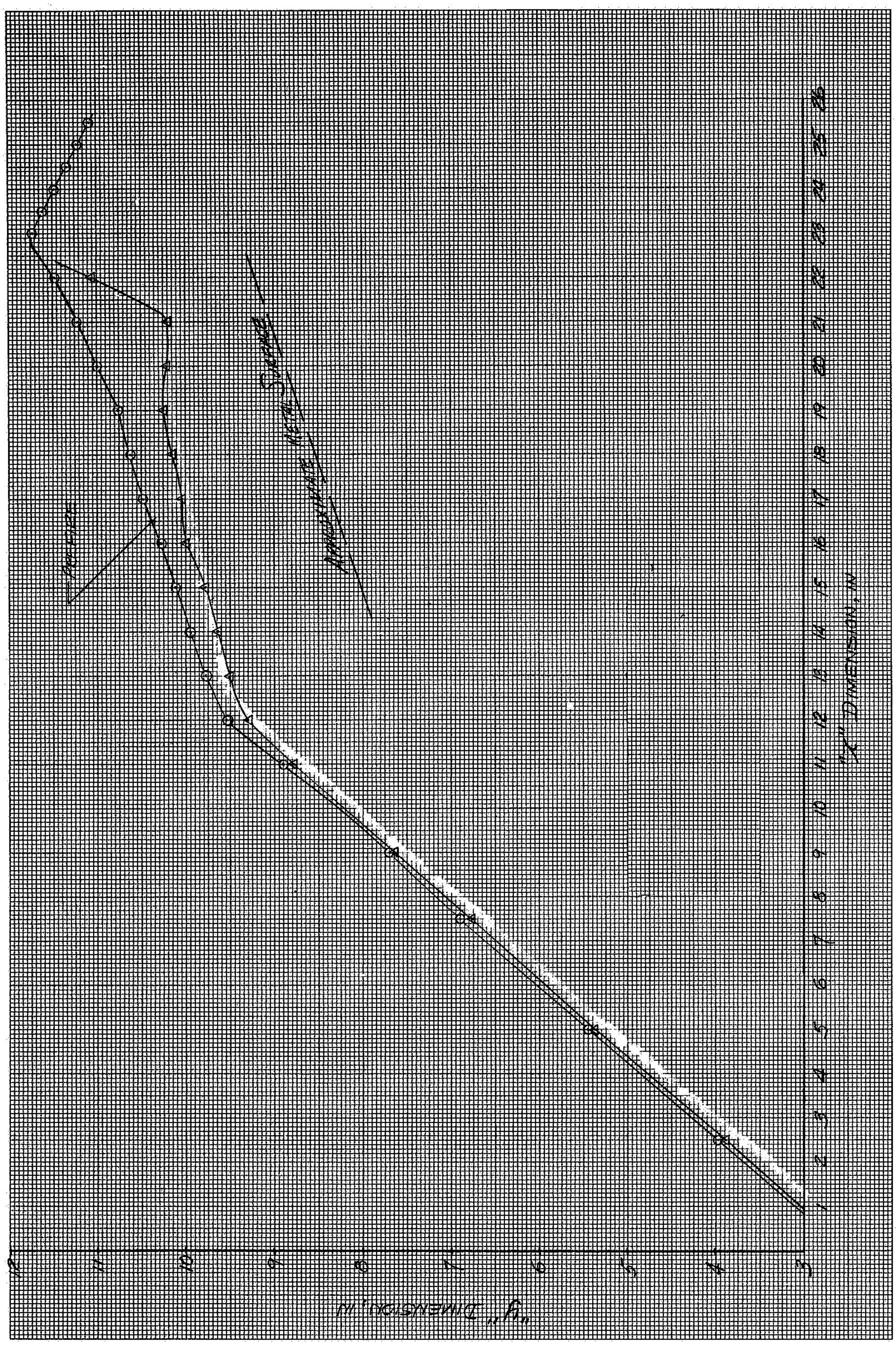
Motor S/N I-2, 315° - IBC-111 Specimen Profile

Figure 16



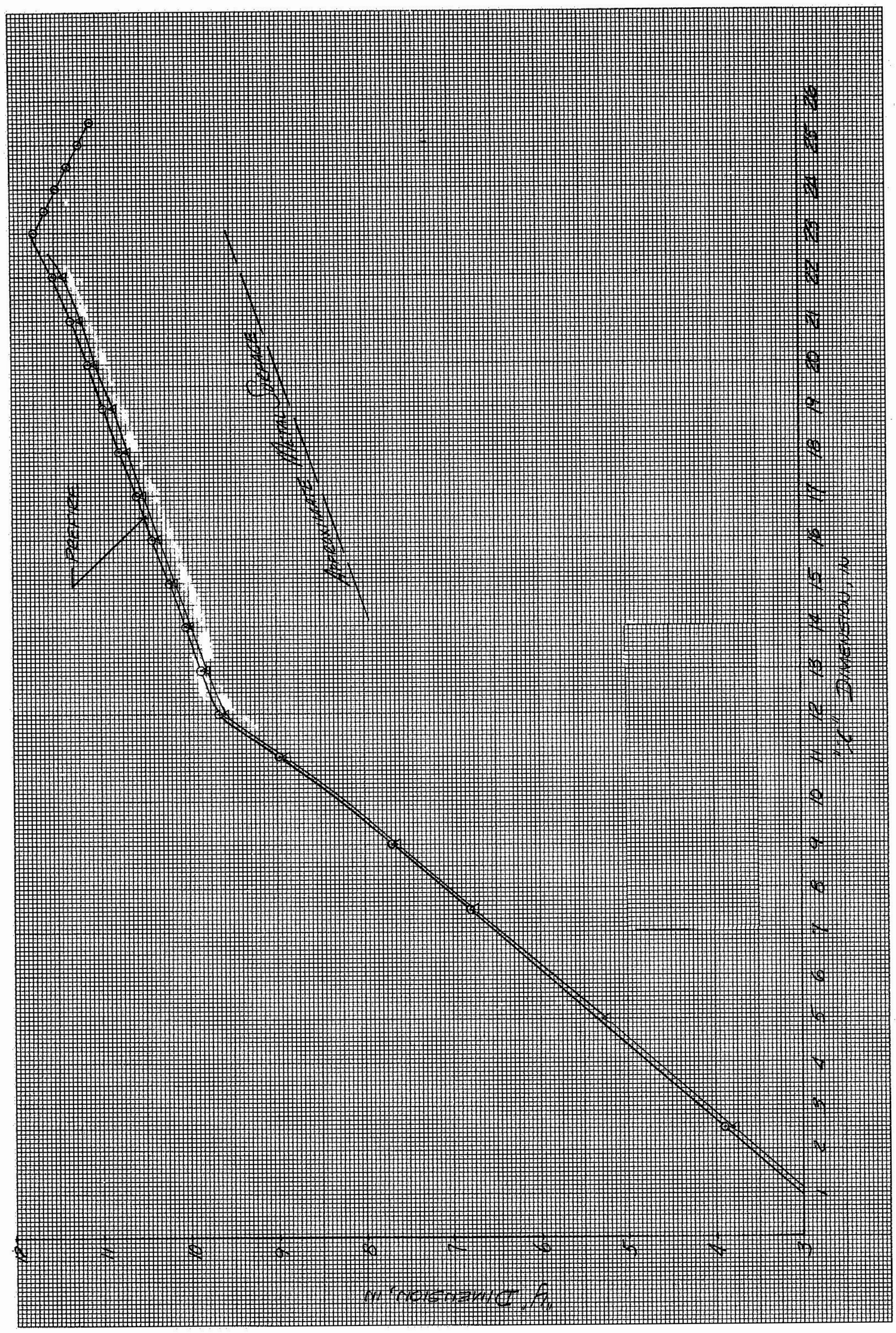
Motor S/N I-3A, 0° - V-44 Specimen Profile

Figure 17



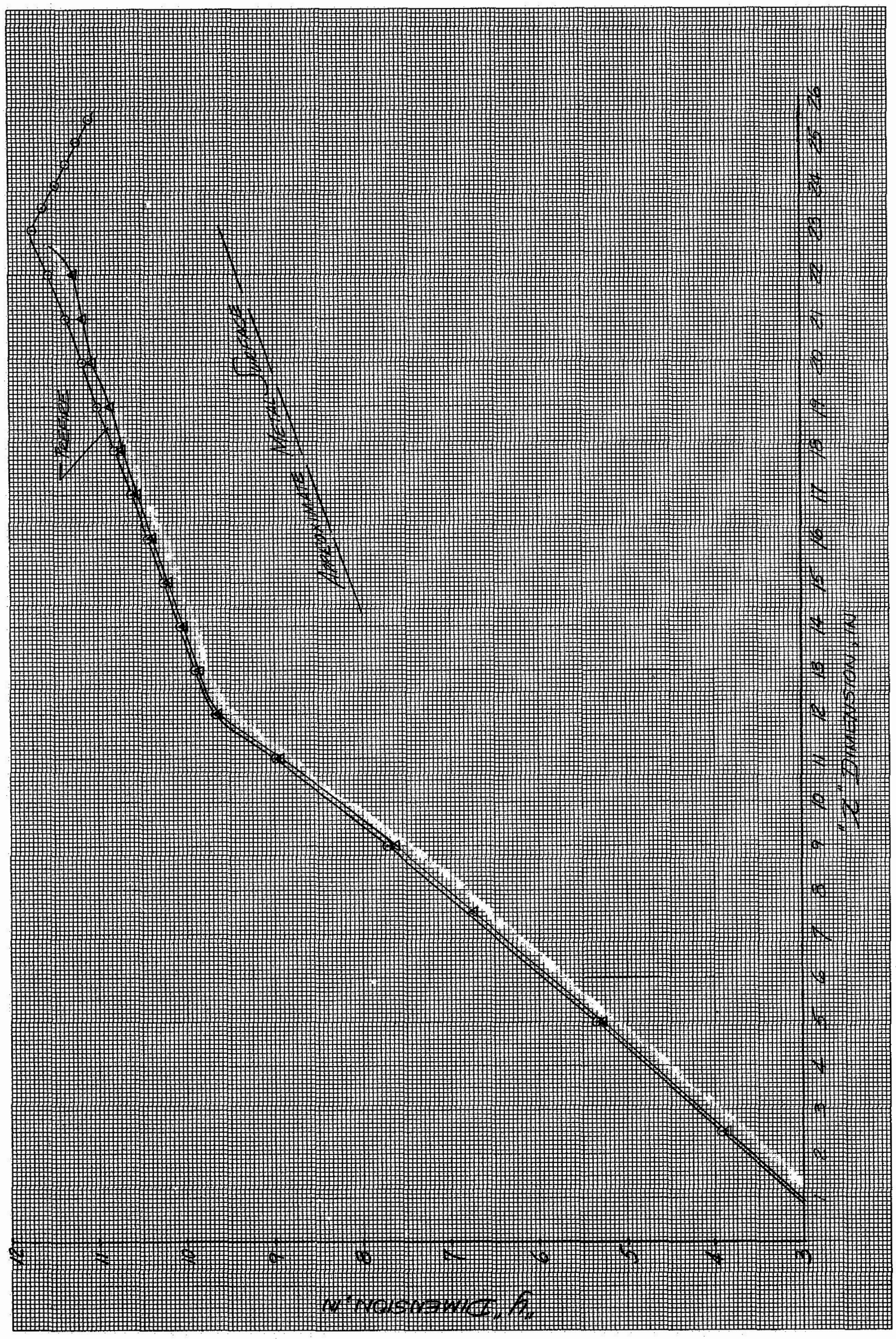
Motor S/N I-3A, 45° - V-61/TI-H704B Specimen Profile

Figure 18



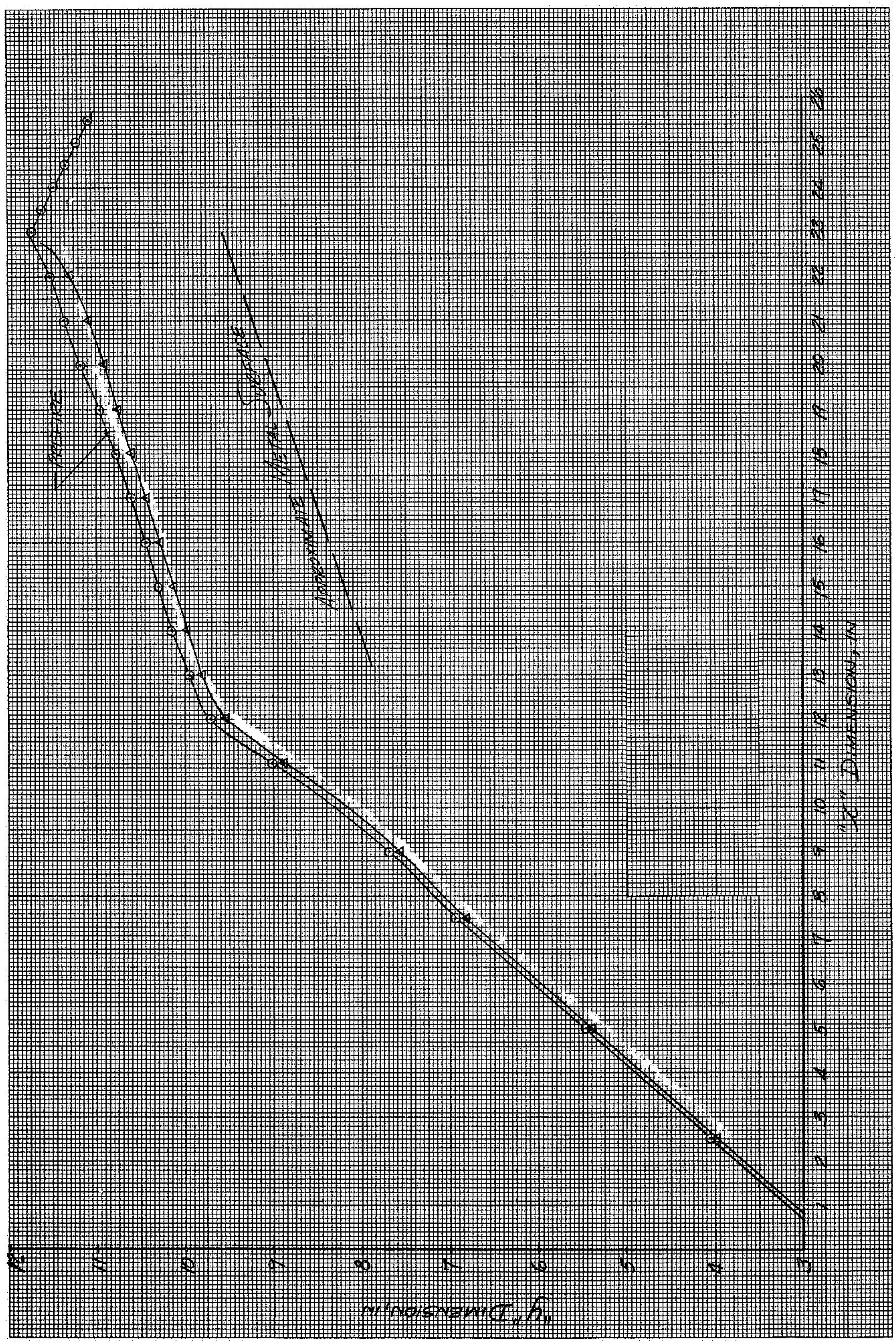
Motor S/N I-3A, 90° - USR-3800 Specimen Profile

Figure 19



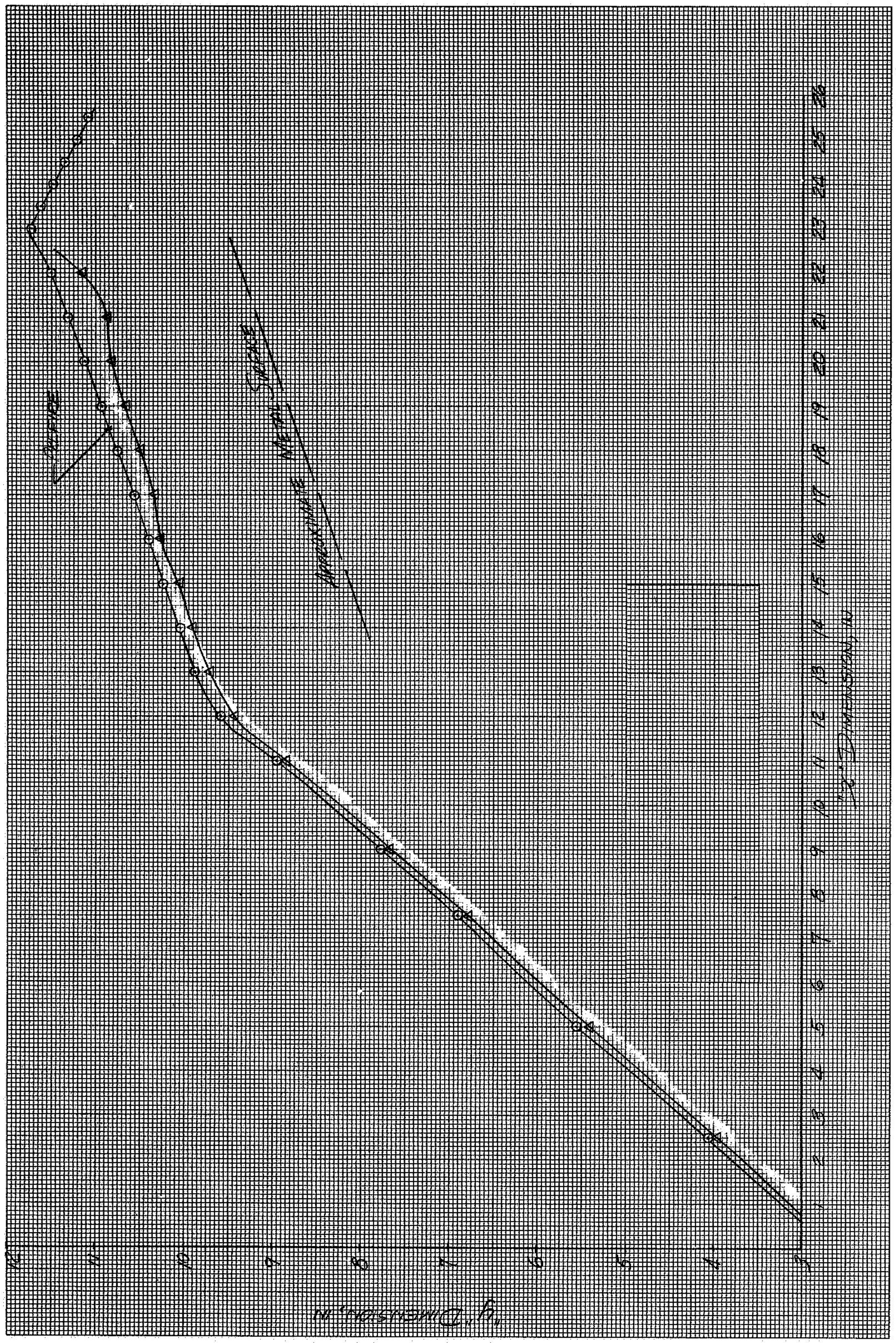
Motor S/N I-3A, 135° - ORCO-9250 Specimen Profile

Figure 20



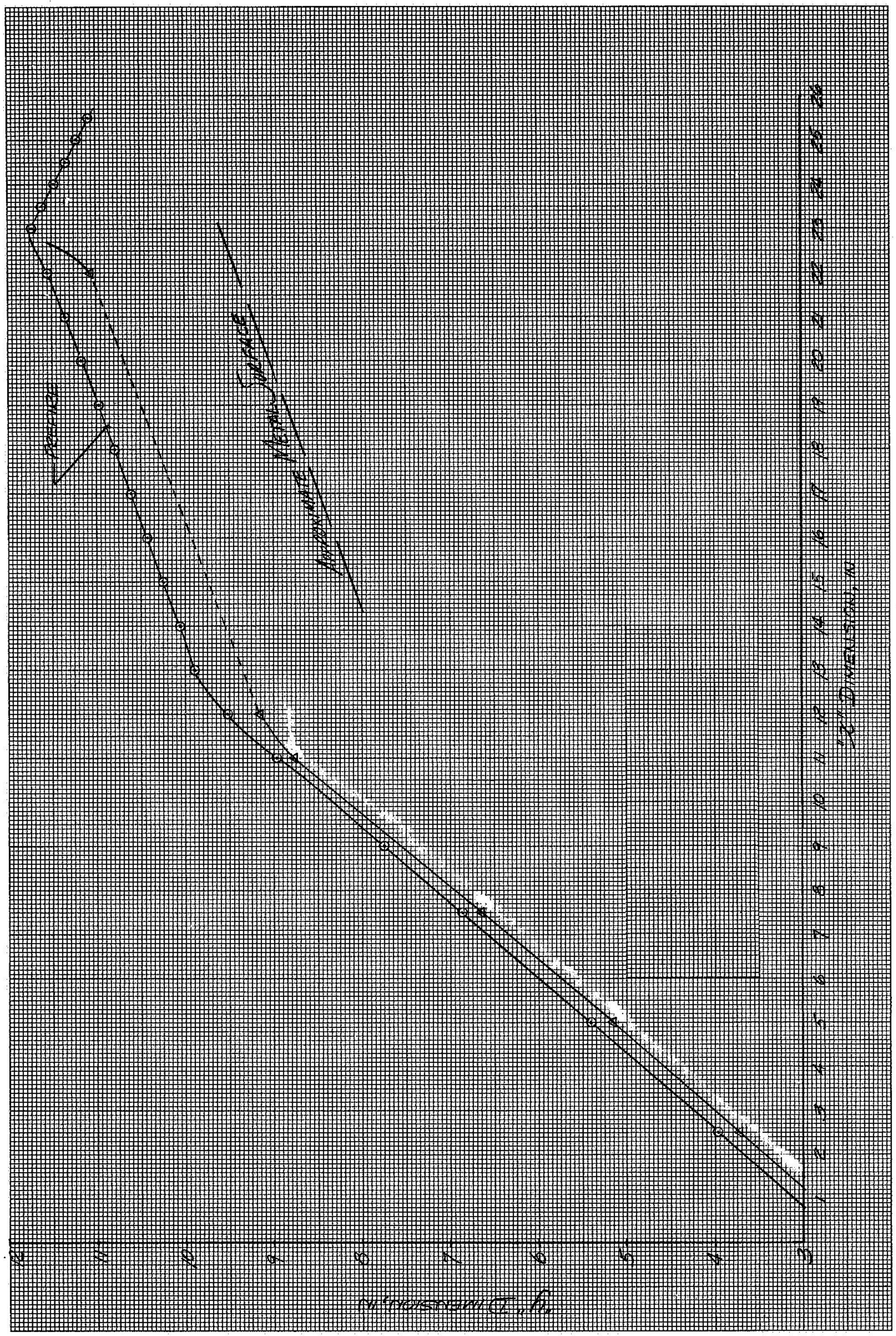
Motor S/N I-3A, 180° - IBT-100 Specimen Profile

Figure 21



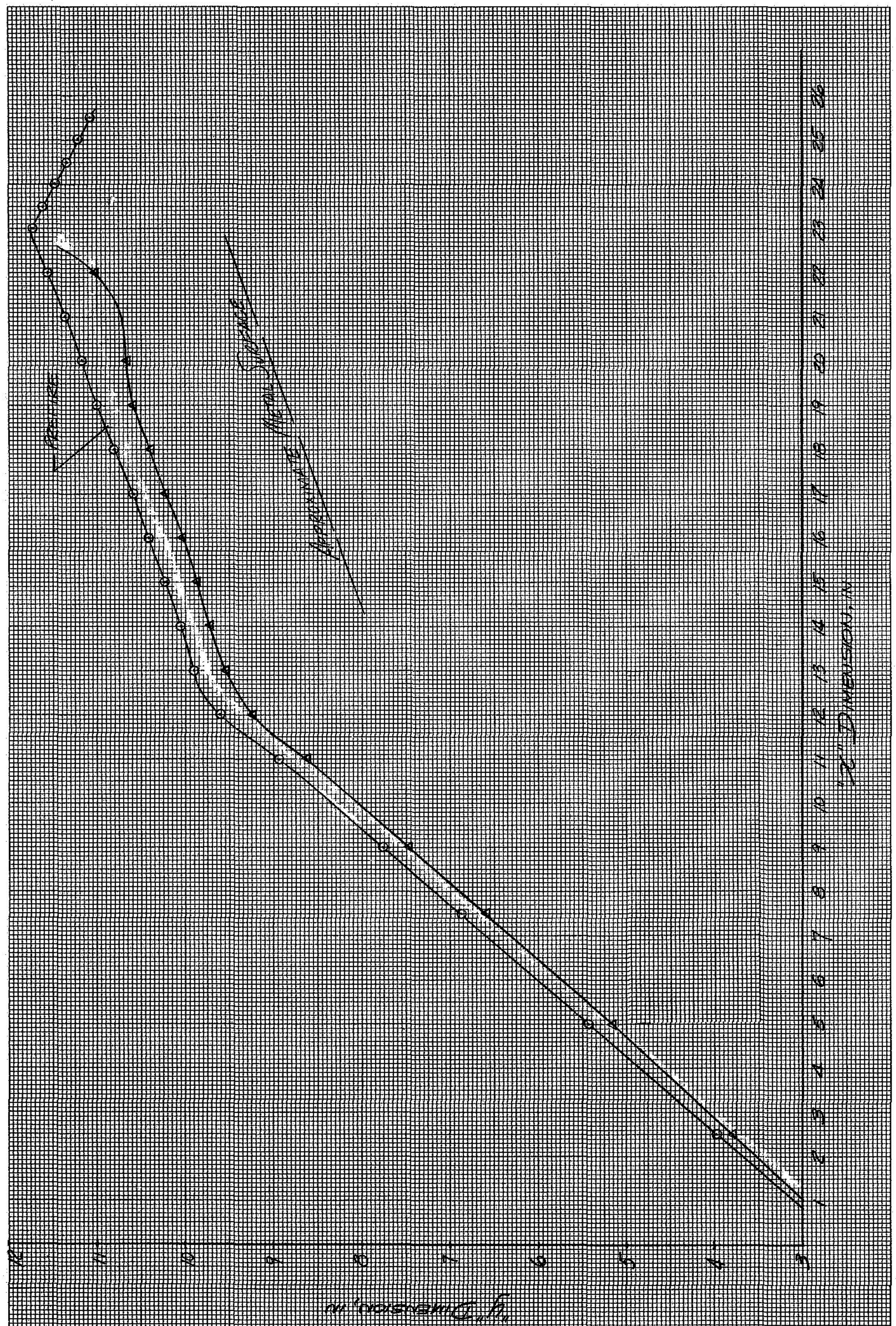
Motor S/N I-3A, 225° - Gen Gard 4011 Specimen Profile

Figure 22



Motor S/N I-3A, 270° - Avcoat 8021 Specimen Profile

Figure 23



Motor S/N I-3A, 315° - USR 3804 Specimen Profile

Figure 24

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